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National Airspace Data Interchange Network (NADIN) Support of Remote Maintenance Monitoring System (RMMS)

NETWORK ANALYSIS CORPORATION
301 Tower Building
Vienna, VA 22180

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December 1981

Final Report

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16. Abstract

NADIN architectural enhancements necessary to support the RMMS and MMS programs are described. Several alternative approaches are formulated. These alternatives are compared and recommendations are made. It is found that:

- The NADIN backbone has sufficient capacity to handle initial RMMS traffic at adequate performance levels.
- An X.25 compatible interface for the NADIN and MPS connection is recommended.
- Additional frame routing capabilities at the NADIN concentrator and front end processors are required.
- Future MPS communications will be best served by a fully distributed packet switched NADIN capable of supporting complete X.25 functions.

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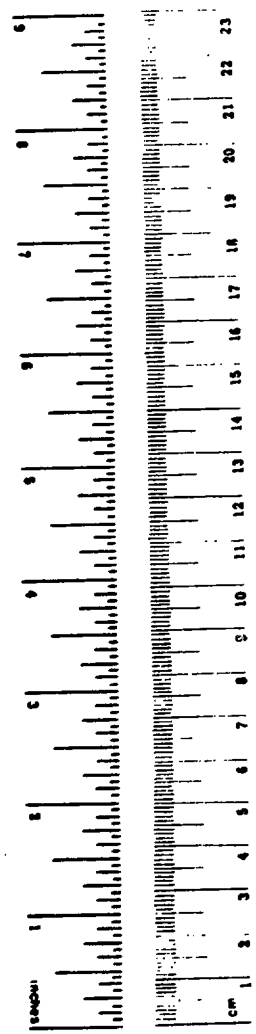
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

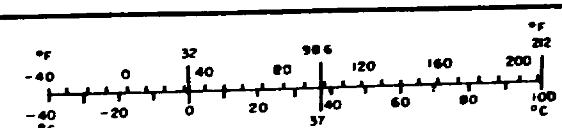
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

The Federal Aviation Administration (FAA) maintains many navigational aides and communications facilities to promote and ensure safe and efficient air traffic flow. Advances in technology are enabling the FAA not only to develop more effective and sophisticated navigation equipment but also to reduce its maintenance and operations cost by developing a comprehensive Remote Maintenance Monitoring System (RMMS). Individual equipment sites will be monitored by Remote Monitoring Subsystems (RMSs) which will report to Maintenance Processor Subsystems (MPSs). Eventually the RMMS system will take on a broad range of support services in addition to remote monitoring and certification of navigation and related equipment. The national Maintenance Management System (MMS), a far-reaching program for automating maintenance, personnel and logistic functions in the Airway Facilities branch (AAF) of FAA will also utilize the MPSs.

The Remote Maintenance Monitoring System/Maintenance Management System requires the support of a communications utility to connect the Maintenance Processor Subsystems (MPSs) and their subordinate Remote Monitoring Subsystems (RMSs) and work centers into an integrated system. It is expected that the National Airspace Data Interchange Network (NADIN) will provide the communications function for RMMS and MMS.

Under FAA Contract DOT-FA79WA-4355, Network Analysis Corporation (NAC) is investigating the technical feasibility of using NADIN to support the communications needs of a number of candidate services, including RMMS. Task 7 of this contract specifically directs that NAC, with input from AAF program personnel, shall formulate a traffic and performance requirements profile for RMMS and determine the architectural extensions and network enhancements to NADIN necessary to support RMMS.

Initial efforts on Task 7 identified RMMS traffic and performance requirements. These requirements were used as the basis for a design analysis which resulted in a set of findings and recommendations regarding NADIN extensions to support RMMS. These activities and results have been synthesized in this document which is Contract Deliverable C3.

1.1 Objectives

The purpose of this study is to determine if and how NADIN can adequately support the communications requirements of the RMMS and MMS programs. NADIN was designed as a common user network to serve initially a variety of non-intelligent terminals, particularly Area B terminals. As new classes of users such as the MPSs appear, NADIN will be called on to provide new services to meet their communications needs. This memo identifies those services and the enhancements to NADIN which will best provide them.

A related objective of this study is to assist the RMMS and MMS programs to design their geographically dispersed processors to function as a coherent system capable of orderly growth in size and sophistication. This system integration is crucial to the success of the RMMS and MMS programs.

1.2 Summary of Findings

The analysis and requirements profile undertaken in this study resulted in a number of conclusions. The highlights of the major results are listed below:

- The NADIN backbone has sufficient capacity to handle initial RMMS traffic at adequate performance levels.

- An X.25 compatible interface for the NADIN and MPS connection is recommended.

- Additional frame routing capabilities at the NADIN concentrator and front end processors are required.

- NADIN can support the X.25 interface for <u>initial</u> MPS communication with <u>no other change</u> in architecture.

- Future MPS communications will be best served by a fully distributed packet switched NADIN capable of supporting complete X.25 functions.

- NADIN concentrator ports must be added - initially one per concentrator, later an average of four additional ports per concentrator.

These and other supporting results are developed in detail in this report.

1.3 Organization

This report is organized into four major sections and nine supporting appendices. The subjects are:

- Section 2 - BACKGROUND - This section presents a brief overview of the RMMS/MMS programs required to understand the data communications issues addressed in this report.

- Section 3 - NETWORKING ALTERNATIVES - This section describes four feasible approaches for NADIN support of RMMS/MMS.

- Section 4 - EVALUATION OF ALTERNATIVES - The alternatives described in Section 3 are compared in a number of areas, including performance, timeliness, flexibility and others.

- Section 5 - RECOMMENDATIONS - An alternative is chosen from among the four. Recommendations for implementing this alternative are made.

The appendices contain the detailed technical basis for the results discussed in the report. In addition, detailed information on implementing the recommendations as well as other information including higher level protocol issues are included.

SECTION 2

BACKGROUND

2. INTRODUCTION

This section presents a high-level description of the RMMS, the MMS and the National Airspace Data Interchange Network (NADIN). This will provide the background for interpreting the results and analyses in subsequent sections.

2.1 RMMS System Description

The Federal Aviation Administration (FAA) uses a large number of geographically dispersed navigational aides (NAVAIDs) to facilitate safe and efficient use of the National Airspace. These remote devices cover a wide range of operational roles and implementation technologies. Each must be periodically certified as to operability, and maintained accordingly. This has been historically accomplished by manning some sites, and scheduling periodic visits to others.

Current technology offers the opportunity to substantially improve the responsiveness of the monitoring and maintenance activities, and at the same time reduce the cost of the present labor-intensive approach. The Airway Facilities Service (AAF) of the FAA has operational responsibilities for the NAVAIDs, and is pursuing numerous applications of current technology to enhance the maintenance and monitoring activities. In particular, AAF has formulated the concept of a Remote Maintenance Monitoring System (RMMS) that will provide the capability to (1) automate and remotely control the periodic tasks of equipment performance monitoring and the recording of certification parameter data and (2) support fault isolation, diagnostic testing, and uplink servo control.

2.1.1 RMMS Functions

The RMMS will replace many routine maintenance functions currently performed at remote equipment sites and will permit them to be accomplished at any suitably equipped work station. Numerous functions have been identified for the RMMS (Reference 8); the

first three functions will be implemented with the initial introduction of RMMS equipment. As state-of-the-art replacement equipment is introduced in the National Airspace System (NAS), and operational experience is obtained with the initial RMMS, the remaining functions may be implemented. These functions include but are not limited to:

(1) Initial

(a) Real-Time Monitor and Alarm
(b) Certification-Parameter Logging
(c) Remote Control

(2) Future

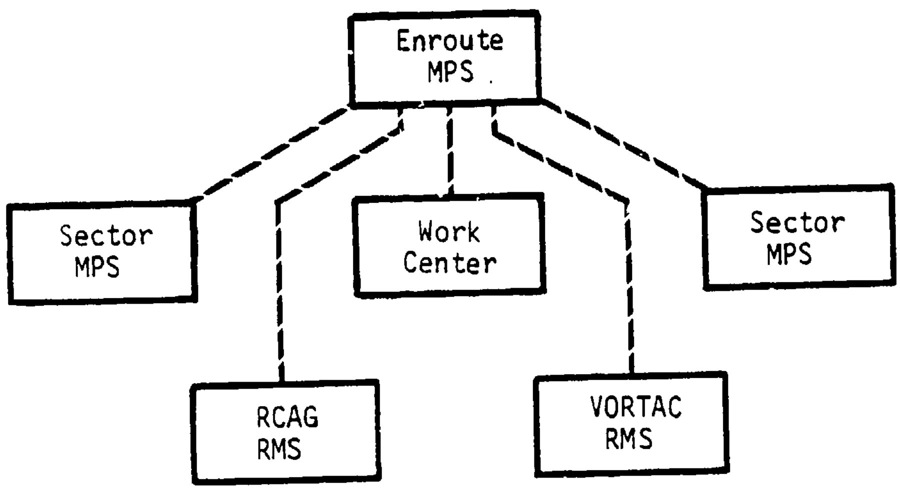
(a) Automatic Recordkeeping and Information Retrieval
(b) System Performance Trend Analysis
(c) Remote Diagnostics
(d) Uplink Equipment Adjustments
(e) Failure Anticipation
(f) Historical File of System Problems and Solutions

2.1.2 RMMS Structure

The RMMS will consist of four types of physical elements. These elements are:

1. Remote Monitoring Subsystems (RMS)
2. Maintenance Processor Subsystems (MPS)
3. Terminal System (both fixed and portable)
4. Telecommunication Network (TCN)

Figure 2-1 is an overall block diagram of the RMMS illustrating the hierarchical relationship between the major elements of the system. The RMS will consist of equipment at the remote facility site to perform facility monitoring, data acquisition, and alarm reporting functions. The MPS will act as the hub of the RMMS to collect, record, and analyze facility data, and to distribute it to appropriate locations. Fixed terminals will be



TCN =

FIGURE 2-1: RMMS STRUCTURE

provided at work centers to enable the MPS to alert maintenance technicians of alarm conditions as well as to permit the technicians to query the MPS for status information. Portable terminals will be used by technicians at facilities to obtain immediate status information on a collocated facility directly or information on a remote facility via the MPS. All information transfers between the MPS and each RMS and the terminal locations will be accomplished through the TCN.

2.2 Maintenance Management System (MMS)

The MMS (Reference 2) will be an administrative and technical support system designed to automate the collection, storage, analysis and distribution of data as well as the monitoring of administrative and technical functions. This system will allow various levels in the Airway Facilities Service (AAF) hierarchy the capability to input, access and process the information required to administer AAF programs efficiently. Examples of some of the many programs which will be managed with the use of this system are:

- Facility logs
- Equipment performance data
- Trouble shooting data
- Logistics inventory
- Equipment failure analysis
- Facilities master file

MMS software will share the Maintenance Processors with the RMMS software. Substantial amounts of data will be provided to the MMS by the RMMS. When required at regional offices, National Headquarters or National Support Group, necessary information can be forwarded upon request or on a scheduled basis via the TCN. The MMS program concept is currently under development. The number, type and location of MMS processors has not yet been determined but tentative plans call for MMS functions at Enroute MPSs,

general NAS Sector MPSs, regional processors and possibly one or more national MMS processors. The full capability of the Maintenance Management System will be phased in with the complete deployment and implementation of the Remote Maintenance Monitoring System. To provide early guidance to the MMS program, this memo qualitatively defines the communications requirements needed for NADIN support of the MMS.

2.3 Implementation Phases

The RMMS program will be implemented in steps over the next 6 to 10 years. For the purposes of this NADIN support study, the RMMS implementation is described in three parts. These are labeled Phase I, Phase II - Scenario I and Phase II - Scenario II. These are described below.

2.3.1 Phase I (1981-1983)

The initial phase of RMMS includes the Enroute MPSs, the Remote Center Air/Ground (RCAG) RMS, the Second Generation VHF Omni Range/Tactical Air Navigation (VORTAC) RMS, the workcenters and the associated fixed and portable technician terminals. This system is being installed in 1981 through 1983. Complete operation of Phase I is scheduled to occur in early 1984. MMS functions at the Enroute MPSs are also scheduled for completion by late 1983. These are included in Phase I but no traffic data is available for MMS. Hence, Phase I traffic does not include MMS traffic.

2.3.2 Phase II, Scenario I (1984-1987)

In the time period 1984-1987, approximately 80 general NAS Sector MPSs are to be installed, one in each AF sector. Possible locations for the Sector MPSs are Air Traffic Control Towers (ATCT), Automated Flight Service Stations (AFSS) or AF Sector Offies. During this period additional systems may be remotely monitored via new RMSs tied to the MPS network. However for a basis of comparison, Phase II - Scenario I is defined as simply Phase I plus the general NAS Sector MPSs. The traffic and throughput computations in Appendix F are based on this definition.

2.3.3 Phase II, Scenario II (1987-1990)

Many facilities are candidates for future remote monitoring. It is not clear yet which of the many candidate systems will in fact be monitored by RMSs or when this will happen. Therefore for sizing purposes Phase II - Scenario II is defined as the RMMS system which would exist if all of today's candidates for RMS systems are implemented. In addition to Phase I and the general NAS Sector MPSs, the Remote Monitoring systems included in Phase II - Scenario II are:

- Radar Microwave Link (RML) - 720 sites
- Medium Intensity Approach Lighting System (MALSR) - 621 sites
- Air Route Surveillance Radar - 89 sites (ARSR-3 and ARSR-4)
- Runway Visual Range (RVR) - 400 sites
- Airport Surveillance Radar (ASR) - 207 sites (ASR-7/8 and ASR-9)
- Approach Lighting System w/Sequenced Flashes (ALSF) - 75 sites
- Instrument Landing System (ILS) - 1028 sites
- Visual Approach Slope Indicator (VASI) - 631 sites
- Remote Transmitter/Receiver (RTR) - 700 sites
- Doppler VHF Omni-range (DVOR) - 60 sites
- Remote Communications Outlet (RCO) - 282 sites (includes FSSs to be closed/part-timed)
- Backup Emergency Communications (BUEC) - 255 sites
- Distance Measuring Equipment (DME) - 310 sites

- Direction Finder (DF) - 293 sites
- VHF Omni-range Test Signal (VOT) - 103 sites
- Non-Directional Beacon (NDB) - 600 sites
- Microwave Landing System (MLS) - 1250 sites
- Beacon Only - 20 sites

Phase II - Scenario II represents the extreme case of 100 percent implementation of all current RMS candidates. This can be compared with the bare bones case of Phase II - Scenario I to obtain upper and lower bounds for expected future requirements of RMMS for NADIN communications support.

2.4 MPS to MPS Communications Overview

Each MPS (Reference 7) will act as a central processing and control point to collect, record, and analyze monitored data and to issue commands to all of its assigned RMSs. The MPS will also be responsible for the display of monitored data and the maintenance of an historical record of reported data. The MPS will receive periodic status and certification reports from the associated RMSs. Alarm conditions will also be reported to the MPS from the RMS upon occurrence Phase I RMMS implementation calls for Enroute MPSs at each Air Route Traffic Control Center plus Oklahoma City and possibly Atlantic City. In Phase II, approximately eighty (80) General NAS Sector MPSs will be installed. Possible locations for these are:

- Sector Offices
- Combined Stations and Towers (CS/T)
- Flight Service Stations (FSS)

Figure 2-2 shows the connections to a typical center MPS in Phase I of the RMMS implementation.

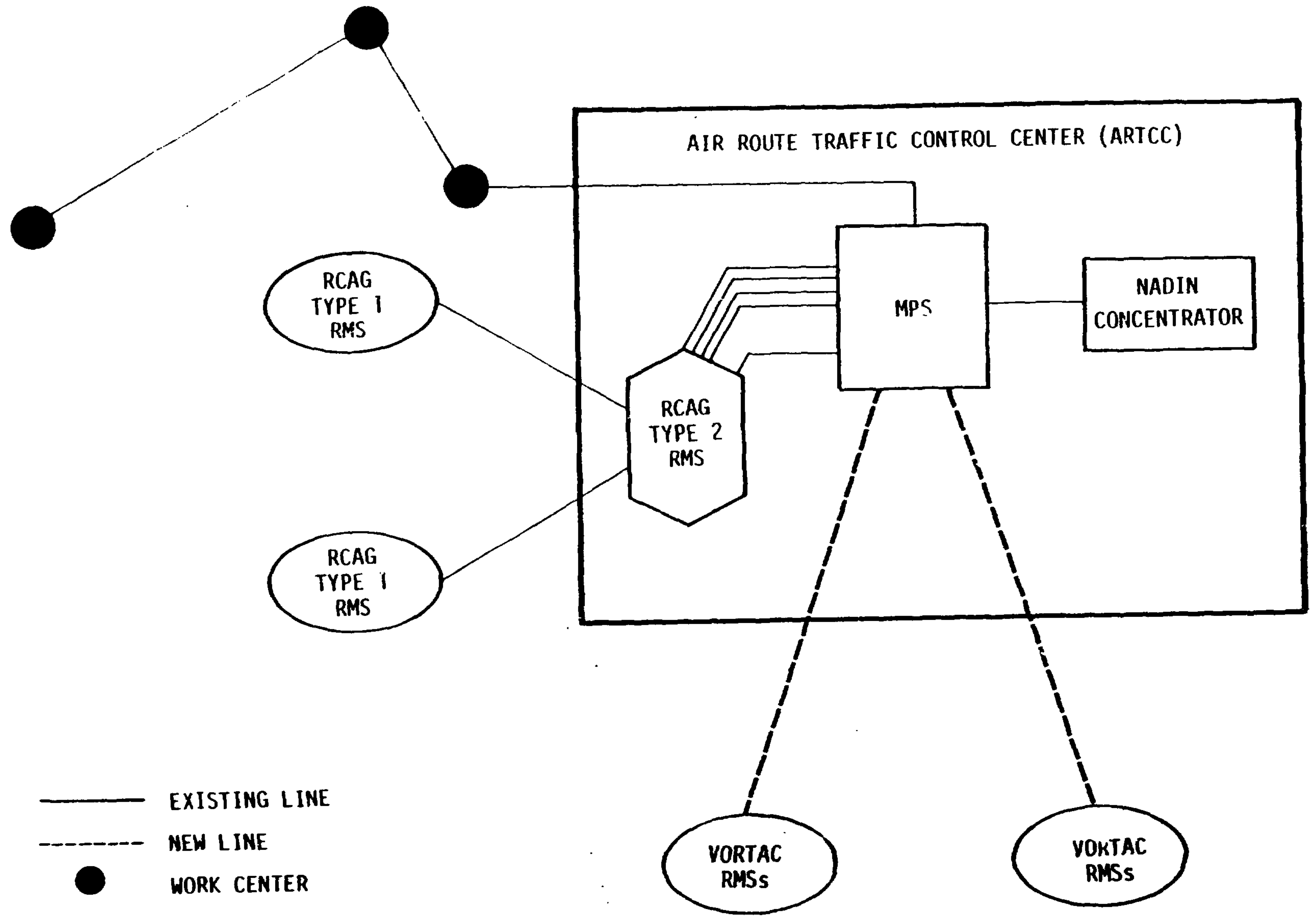


FIGURE 2-2: RMMS PHASE I - CENTER MPS AND CONNECTED ELEMENTS

The Enroute MPSs will be Tandem T16 minicomputers located at the ARTCC while the general NAS Sector MPSs have not yet been selected. These machines perform monitoring, certification assistance and record keeping tasks for the various Remote Monitoring Subsystems as well as communications support for fixed and portable terminals.

A detailed description of the Remote Maintenance Monitoring System is provided in Appendices A and B. The MPS will also house the MMS software. Details of how MMS will function and its precise relation to RMMS software are not yet determined. In addition, the MPSs will collect, store and retrieve data for the national Maintenance Management System (MMS) (Reference 16). To understand the architectural enhancements required by NADIN to support MPS to MPS communications, it is necessary to characterize the functions of this system.

2.4.1 MPS to MPS Functions

In the initial phase of the RMMS, traffic from MPS to MPS will consist of:

- alarm messages - short, high priority messages requiring end-user acknowledgement,

- file updates - short to medium (1,000 characters) status or certification reports,

- free format terminal requests - technicians requesting support data to assist in diagnosing or effecting repairs,

- replies to data base queries - short to medium length responses to MPS-generated or human-generated requests.

In later phases of the national Maintenance Management System, large scale file updates and perhaps file transfers will become common between MPSs. The initial concept is that only MPS computers and their subsidiary terminals will exchange information. However, the possibility should not be excluded that in the future it may be desirable to allow access to other authorized users. Possible candidates are the ATC computer (9020 or 9020R) and the flow control computer in Jacksonville.

2.4.2 MPS Traffic

The bulk of MPS to MPS traffic will be between Enroute MPSs and Sector MPSs in the same enroute air traffic area. (Throughput details are discussed in Appendix A.) Most of the remaining traffic is between MPSs, both Enroute and Sector, in adjacent enroute areas. All RMMS and MMS traffic which enters NADIN uses the MPS/NADIN concentrator interface.

Several observations can be drawn from the above overview of MPS to MPS communication.

- MPS traffic does not require the message processing functions of the NADIN message switch,
- MPS traffic requires local routing from NADIN,
- RMMS/MMS needs efficient handling of large files,
- RMMS alarms require fast delivery (3 second MPS to MPS delay),
- RMMS traffic patterns do not follow the NADIN double star topology.

The possible networking approaches to provide NADIN support of MPS to MPS communication are discussed in the next section. A number of higher level protocol issues for MPS host-to-host consideration are discussed in Appendix G.

2.5 The National Airspace Data Interchange Network (NADIN)

The FAA is in the process of implementing a common user data communications network scheduled for operation by the third quarter of 1983.

NADIN is currently being developed as a centralized network. It includes two interconnected, centrally located, message-switch nodes. These are each connected by a

star-patterned subnetwork to eleven or twelve concentrator nodes. Figure 2-3 illustrates the basic elements of the NADIN concept. Under the Level IA implementation the link between a switch and each associated concentrator consists of one full-duplex, voice-grade line, operating at 9,600 bits per second (b/s). The link between the two switches consists of two such lines. The two switches, the twenty-three concentrators and the links interconnecting them make up the NADIN backbone network. The complete network can be considered to also include the various ATC data terminals and computers which use the NADIN facilities and the circuits and subnetworks by which they are linked to the backbone network.

Typically, a NADIN message is directed from the originating data terminal or computer through a concentrator to the associated switch. The switch then routes the message to its destination (terminal or computer) by way of the other switch, if necessary, and the concentrator to which the destination is linked. Variations to this typical routing include local switching at the concentrators for certain message traffic and the entry/exit at the switches for message traffic involving external systems (e.g., WMSC and International AFTN).

The NADIN concentrators are intelligent statistical multiplexors. Their major functions include:

- limited message processing, e.g., code and format conversion;
- local switching of pertinent traffic, including the collection and periodic forwarding of statistics on such traffic to the central switch;
- application of link-level protocols, including the fragmenting/reassembly of messages into/from ADCCP frames;
- buffering of messages; and
- multiplexing/demultiplexing of message frames.

Each switch consists of two major components - a front-end processor (FEP) and a message processor (DS 714). The FEP is functionally and physically similar to a NADIN concentrator. It performs the actual switching functions. All links to the NADIN switch are

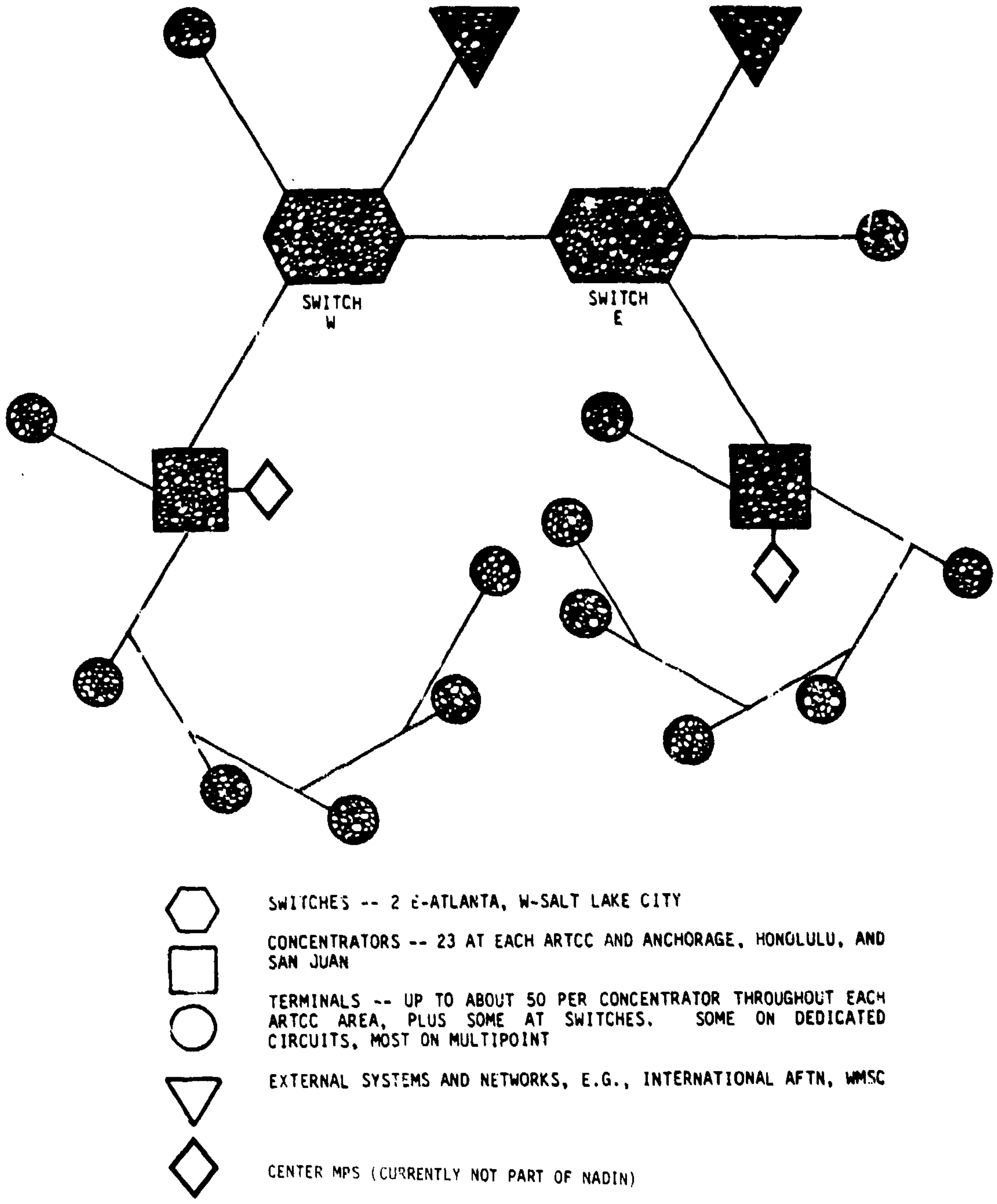


FIGURE 2-3: NADIN SCHEMATIC

through the FEP. The DS 714 is a computer with associated peripheral equipment (e.g., tape and disk drives). Its functions include:

- message editing,
- message routing,
- message recording/recovery,
- accounting, and
- network control.

SECTION 3

NETWORKING ALTERNATIVES FOR NADIN SUPPORT OF RMMS

3. INTRODUCTION

Four feasible networking approaches to provide MPS to MPS communications via NADIN are described in this section. All of these candidates take as starting points the NADIN IA architecture and the MPS to MPS communications requirements outlined in Section 2.

3.1 Alternative 1

The first approach for NADIN to satisfy MPS to MPS requirements is to make minimal modifications to NADIN IA. That is, NADIN retains the double star topology with message processing at the switch. In particular, no new backbone nodes are added. In this approach, the MPS would deliver data to the NADIN concentrator as messages segmented into frames in the manner of the FSAS/NADIN interface (Reference 3). The messages would be limited to 3700 characters, the frames to 245 characters (NADIN standards). Message format would be the NADIN information message format (Reference 4).

The concentrator would scan the message, build a NADIN transport header as described in Reference 5, and ship the message upstream, frame by frame, to the NADIN message switch for routing. The NADIN message processor at the switching center would also check the MPS message for format errors just as it does for teletype messages before passing the message on through the network for delivery.

The exception to this procedure is for local traffic, i.e., origin and destination in the same Enroute Area, which can be routed by the concentrator itself. Local switching of RMMS traffic constitutes an enhancement of the limited local switching capability to be included in NADIN IA for FDIO traffic.

3.2 Alternative 2

This alternative retains the topology and hardware configuration of NADIN IA. However, there are several significant changes in the way the MPS passes data to the network and the way in which the routing function is carried out.

The MPS passes data to the NADIN concentrator in frames, maximum length of 256 characters including link level headers and trailers. Each frame contains a transport header supplied by the MPS, not by NADIN. The first four octets of this transport header contain priority and addressing information. The latter portion of the transport header is for use by the two communicating MPS hosts and is ignored by NADIN.

The NADIN concentrator reads the transport header address and, assuming it is a recognizable non-local network address, passes the frame upstream to the front end processor (FEP) at the switching center. The FEP, based on the transport header, routes the frame to the appropriate network exit point (concentrator). Routing is fixed. The frame never goes to the message processor (DS 714). Consequently these frames are not retrievable from NADIN, unlike NADIN accountable message traffic. The MPS takes this responsibility.

Local traffic will be switched by the concentrator itself without the involvement of the FEP.

3.3 Alternative 3

This alternative retains the NADIN IA topology but requires the enhancement of NADIN to support X.25 interfaces. However, NADIN would not initially become a packet-switched network internally. The MPS would present packets to the NADIN concentrator. Virtual circuits between the MPS hosts would be established by call request and call accept packets. Datagram service might also be used by the MPSs. However, internally NADIN would not move the packets via virtual circuits. This concept of virtual circuits supported by an underlying network without virtual circuits is discussed in Reference 6.

The NADIN FEP and concentrators would also be modified as in Alternative 2. The concentrator would perform local switching for local traffic while packets for remote addresses would be forwarded to the FEP at the NADIN switching center. The FEP would route this traffic directly to the appropriate NADIN concentrator. As in Alternative 2 the packets from the MPS would completely bypass the message processors (DS 714s) at the NADIN switching centers.

The mechanism for conveying routing information from the concentrator to the FEP would be a concentrator built transport header as described in Reference 5.

The NADIN concentrator would require software modifications to establish a mapping between virtual circuit numbers (permanent or temporary) and network addresses. The NADIN exit point would have to do the reverse mapping, possibly holding packets for correct sequencing, then passing the packets to the receiving MPS with the expected virtual circuit number appended.

This alternative provides the MPSs with the ability to interface to a packet-switched network. If and when NADIN becomes a full packet-switched network the MPS/NADIN interface would require virtually no additional modification.

3.4 Alternative 4

This alternative consists of the MPS interfacing to NADIN via X.25 to a packet-switched NADIN with increased connectivity. Additional backbone links would be added to NADIN as proposed in NAC's Computer B Report (Reference 8). A possible configuration is shown in Figure 3-1. Note that NADIN IA backbone nodes are retained under alternative four. The composition and function of the nodes would be changed, however; e.g., packet switch modules (PSMs) would be added. Under the NADIN IA architecture, there are two types of nodes:

- message-switch nodes at the Atlanta and Salt Lake City ARTCCs, which also include concentrators; and
- concentrator nodes at the 18 other CONUS ARTCCs and at three off-shore ARTCCs (Anchorage, Honolulu and San Juan).

Alternative 4 would result in three types of nodes:

- combined message-switch, packet-switch nodes at the Atlanta and Salt Lake City ARTCCs, which would also include concentrators;
- packet-switch nodes at the 18 other CONUS ARTCCs, which would also include concentrators; and
- concentrator nodes at the three off-shore ARTCCs.

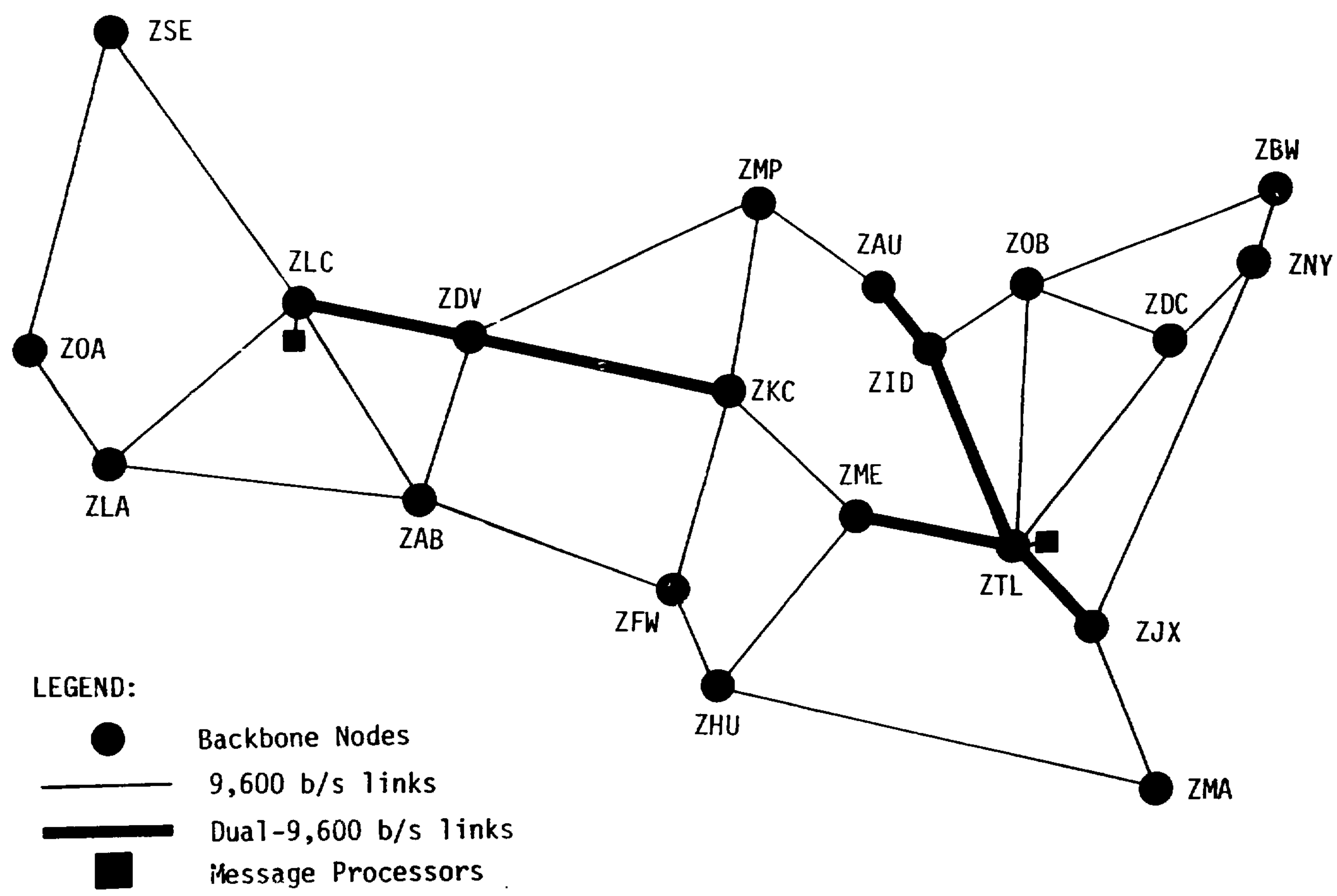


FIGURE 3-1: OPTIMAL ALTERNATIVE 4 CONFIGURATION

The three off-shore nodes would remain essentially unchanged for this initial Distributed Packet Switched Network application. This is practical since it would be unlikely that they would be selected as part of alternate routes for messages between other nodes, and they are not expected to generate much NADIN backbone traffic. Each of the off-shore concentrators would be linked directly to the PSM at a convenient packet-switch node. Those concentrators would thus be functionally modified in the same manner as the other 20 concentrators.

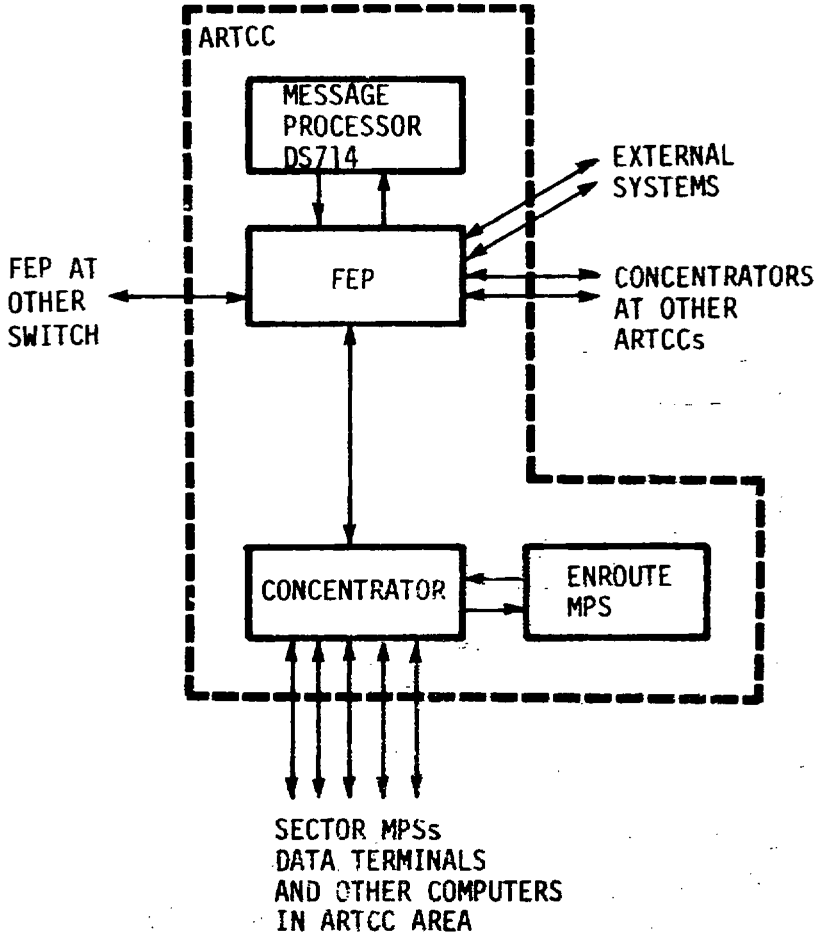
The modifications to the two message-switch nodes are indicated in Figure 3-2. The major change is seen to be the addition of the PSM and the transfer of the major switching function from the FEP to the PSM. The FEP would continue to serve as the front end for the DS 714 and as a gateway for external systems. The concentrator would continue to serve as the backbone network access point for ATC and other data terminals and computers.

The other CONUS nodes would also be modified to include PSMs. This is illustrated in Figure 3-3. Under this enhanced architecture each such node would be linked to a number of other such nodes through their respective PSMs. In general, this need not include a direct link to the PSM at a message-switch node.

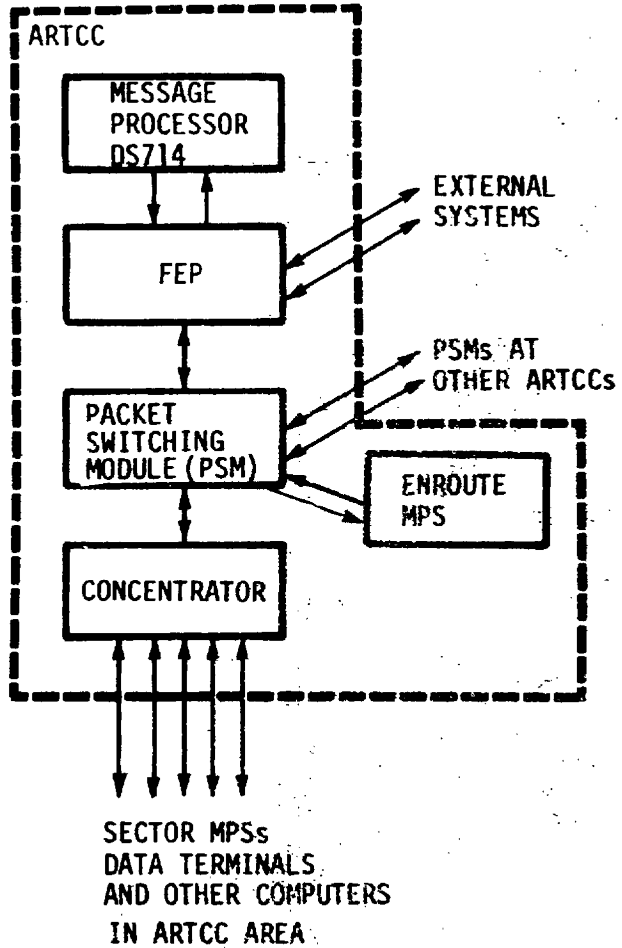
Since not all messages will be directed through the message-switch node under the enhanced architecture, statistical accounting of network traffic must be performed at the packet-switch nodes. The PSMs would perform the accounting relative to packet traffic. The concentrators would perform the accounting relative to message traffic. Pertinent data would be forwarded to the message switch periodically in control messages.

The enhanced NADIN architecture would require some form of virtual circuit service. Such a service would assure the efficient handling of large files and reports without the need for modification of host computer (e.g., MPS) software. For general efficiency this service might best take the virtual call form, with buffering and sequencing provided at the receiving concentrator (or associated PSM). Permanent virtual circuit service would appear desirable for messages between adjacent enroute areas with overlapping facility responsibilities. Datagram service would appear optimal for alarm messages. The ability to handle efficiently the complexities of identifying and separately servicing the various classes of message traffic would require further study.

From the RMMS side, Alternatives 3 and 4 appear the same except for (probably) better NADIN performance under Alternative 4. The MPS/NADIN interface would be X.25 as discussed in Alternative 3 with the MPS presenting packets directly to the NADIN Packet Switch Module at the concentrator.

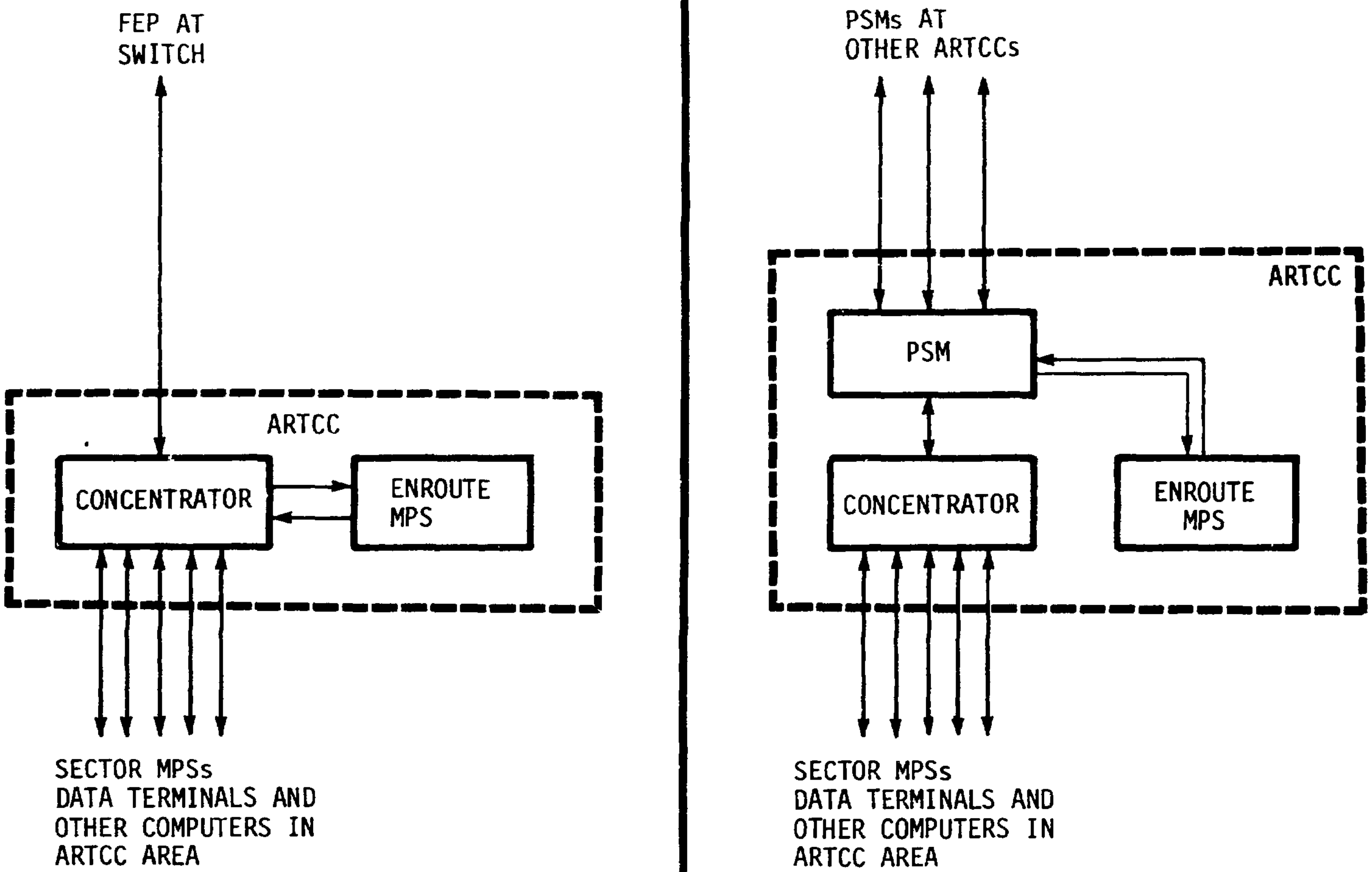


A. ALTERNATIVE 1



B. ALTERNATIVE 4

FIGURE 3-2: MODIFICATION OF MESSAGE-SWITCH NODES



A. ALTERNATIVE 1

B. ALTERNATIVE 4

FIGURE 3-3: MODIFICATION OF OTHER CONUS NODES

SECTION 4

EVALUATION OF ALTERNATIVES

4. INTRODUCTION

The alternatives formulated in the preceding section are compared below. In the long term, it is judged that NADIN should follow Alternative 4, the full packet-switched approach. However, timing factors point to Alternative 3, the X.25 interface plus NADIN IA architecture, as the best approach to satisfy initial RMMS and MMS requirements.

In subsequent sections the alternative approaches are analyzed from several points of view. In Section 4.1 the enhancements to NADIN to support each alternative are discussed. In Section 4.2 a detailed analysis of network performance (throughput and delays) is presented for Alternative 1. Quantitative performance values are not derived for the remaining alternatives. However, their expected performance relative to Alternative 1 is discussed briefly. The alternatives are compared in Section 4.3 for effectiveness, efficiency, timeliness, RMMS futurity and NADIN futurity.

The recommended alternative and the NADIN/RMMS interface are described in detail in Section 5.

4.1 Enhancements to NADIN by Alternative

This section describes the enhancements to NADIN required to satisfy RMMS requirements for each of the four network alternatives defined in Section 3.

4.1.1 Alternative 1

The enhancements to NADIN IA are separated into those needed for Phase I and Phase II of RMMS and MMS as described in Section 2.

In Phase I:

- All NADIN IA link capacities are adequate for RMMS traffic in the near term.

- NADIN concentrators and switches are adequate to handle the increased processing load imposed by RMMS.

- A single medium-speed (2400 bit/sec) port will be needed at each NADIN concentrator for the Enroute MPS.

- Software must be modified to include RMMS ports in NADIN address tables and to carry out other table expansions.

In order to support RMMS traffic in Phase II several enhancements and/or architectural extensions are required for NADIN. These are:

- Ports - At each NADIN concentrator an average of four additional ports (2400 bit/sec) will be needed for the Sector MPSs. In addition, the Enroute MPS port must be upgraded to 4800 bit/sec for Phase II Scenario I. If and when traffic rises to the levels of Phase II Scenario II the Enroute MPS interface to NADIN must be increased to accommodate a peak flow of 10,000 bit/sec. If the full implementation described for Phase II - Scenario II actually occurs then either dual 9.6 Kb/sec ports or a biplexed 19.2 Kb/sec connection would be required. It is difficult to predict with confidence when or if this level of throughput across the NADIN concentrator/Enroute MPS port will occur. For the period 1984-1987 at least, it is likely that a 9600 bit/sec interface will suffice. It is only at the point when more than approximately half of the candidate sites of Phase II - Scenario II for RMS are implemented that 9.6 Kb/sec will become inadequate.

- Local Switching - An enhanced local switching capability is required at the NADIN concentrators to switch local traffic between the Enroute MPS and Sector MPSs. In NADIN IA this function is provided only for FDIO traffic.

- Processor Capacity - Throughput at the NADIN concentrators will rise dramatically in Phase II. Under Scenario II the total gross input into the busier

NADIN concentrator will rise to nearly 21,000 bit/sec, approximately triple the NADIN IA base level of 6,900 bit/sec (gross bits including overhead). While it is possible that the full Scenario II load may not be realized by 1990, there will in any case be a very significant increase in the concentrator processing load in the late 1980s. The reason for this is that traffic between Sector MPSs and their local Enroute MPS will be locally switched by the NADIN concentrator. Table 4-1 shows the input sources to the NADIN concentrator. NADIN IA gross traffic is derived in Appendix D, based on Table Z-9, Reference 4.

The precise capacity and design of the Level IA concentrators is not yet determined. Thus a quantitative assessment of the increase needed in processor capacity is not possible. This is an area which can be identified as important for further study as NADIN and RMMS development progresses. However, this is precisely the type of incremental capacity expansion which the modular design of the NADIN concentrators is intended to facilitate.

- NADIN Backbone Capacity - NADIN IA link capacities are sufficient to handle Phase I and Phase II - Scenario I of RMMS with no difficulty. No increases in trunk capacity are needed to satisfy NADIN end to end delay requirements for either of these two cases. However, this assessment is based on the assumption that no additional traffic beyond NADIN IA and RMMS uses NADIN. By 1987-1990 it is likely that additional users such as NAS-to-NAS and others will be added to NADIN. However, based strictly on NADIN IA, plus RMMS, the traffic load under Phase II - Scenario II could be supported by NADIN IA link capacities. However, utilization would be near critical levels (.70) on the heaviest links which would create extreme sensitivity to any unplanned traffic growth. The cumulative effect of adding RMMS, NAS-to-NAS and other traffic to NADIN is being examined by NAC under Task 13 of this contract.

4.1.2 Alternative 2

Under Alternative 2, backbone and port requirements are the same as for Alternative 1. However, processing loads at the NADIN concentrator and switch should be reduced significantly since virtually no message processing is done by either concentrator or

SOURCE*	NO. OF PORTS	ENVIRONMENT			
		NADIN IA	RMMS PHASE I	RMMS PHASE II SCENARIO I	RMMS PHASE II SCENARIO II
IA Base	29	6,900	6,900	6,900	6,900
E MPS	1	-	330	1,580	10,000
Sector MPS	4	-	-	70	1,600
NS (RMMS)	1	-	330	330	2,170
TOTAL		6,900	7,560	8,880	20,670

* LEGEND:

IA = NADIN IA
E MPS = ENROUTE MPS
Sector MPS = GENERAL NAS SECTOR MPS
NS (RMMS) = NADIN SWITCH TRAFFIC - RMMS ONLY

TABLE 4-1: GROSS INPUT TO NADIN CONCENTRATOR (BIT/SEC)

switch. Unlike Alternative 1, the NADIN concentrator under this alternative does not need to build the NADIN transport header for RMMS traffic.

Software modifications at both the concentrator and front end processor are required to enable NADIN nodes to recognize the MPS transport header and to take appropriate routing action based on it. Included in this routing is local routing by the concentrator. A substantial address table would be required at the FEP to carry out its expanded routing responsibilities under Alternative 2. However other NADIN traffic, particularly data from teletypes and non-intelligent terminals, will be handled exactly as in NADIN IA. Hence virtually no modifications to the message processors at the switching centers are required.

4.1.3 Alternative 3

Under Alternative 3, NADIN backbone and port requirements are the same as for Alternatives 1 and 2. The FEP routing enhancements are essentially the same as in Alternative 2. At the NADIN concentrator, the X.25 RMMS/NADIN interface will require considerable software modification. Since NADIN will not be using virtual circuits internally in this scenario, software will have to perform the exchanges with the MPS and the network needed to make the end-to-end connection appear to be a virtual circuit to the two MPS end users. Dynamic tables linking messages, origin-destination pairs and virtual circuit numbers will have to be maintained at the network exit and entry points. Buffer space must be allocated at the network exit concentrator to store frames/packets for possible resequencing. Analysis would be needed to determine the required amount of additional concentrator buffering required for this alternative. The processing load at the concentrators will increase somewhat due to the overhead of converting packets into NADIN frames and reverse.

The outstanding feature of Alternative 3 is that the MPSs themselves are easy to modify for the X.25 interface. The machines being used (at least for the Enroute MPS) are Tandem T16s which are available with an optional off the shelf X.25 software package (GUARDIAN/EXPAND).

4.1.4 Alternative 4

Under Alternative 4, port requirements would remain about the same as for the other alternatives but throughput across the MPS/NADIN interface could be slightly reduced due

to the savings in overhead gained by the virtual circuit approach. Backbone links would be added to make NADIN more highly connected and allow for alternate routing and congestion avoidance. Packet Switch Modules (PSMs) or the enhancement of the concentrators and FEPs to perform the function of PSMs would be needed at 20 CONUS ARTCCs and two switching centers.

Software changes at the concentrators, FEPs and message processors would be needed. Routing functions would have to be distributed throughout the network. Network control must become more distributed. Certain classes of messages would however continue to be routed to the message processor for editing and retrieval purposes just as in NADIN IA.

4.2 Performance Analysis

An analysis of network throughput and delay was performed to determine the adequacy of NADIN backbone capacity and interface speeds. For Alternative 1, the NADIN IA approach, detailed network queueing models were used to obtain average delays under various loads. For Alternatives 2 and 4 delays would be less than for Alternative 1 because the time consuming message processing at the switching centers is eliminated. However, a quantitative analysis for these scenarios is beyond the resources of this study. For Alternative 3 the additional processing and address translation are expected to cause delays that would be slightly greater than those for Alternative 1. The net result of the performance analysis is to show that the NADIN IA backbone capacity is sufficient for Alternatives 1, 2, 3 and 4 at least for Phase I and Phase II - Scenario I. However Alternative 4 also assumes additional links to provide alternate routing; hence, Alternative 4 performance should be substantially better than Alternative 1 performance.

4.2.1 Alternative 1 - Phase 1 Performance

In the initial phase (1983-1984), introduction of RMMS traffic between Enroute MPSs will have a minimal effect on the NADIN backbone links. Specifically:

- NADIN throughput will increase on the busiest link by a maximum of 6.3 percent above NADIN IA base level to a utilization of .508.

- Average NADIN network delays from a concentrator to a switch to the other switch to a concentrator will increase approximately 3 percent. These delays are:

  - 1.81 seconds - during file transfer periods, and
  - 1.07 seconds - in the absence of file transfers

- NADIN will continue to meet the average end-to-end delay requirement of 2 seconds required by the NADIN Specification.

The computation of delays is discussed in detail in Appendix F. All delays are for peak hour.

One of the important questions in this feasibility study was the adequacy of the service which NADIN would provide to RMMS. The answer for the near term is that NADIN will more than meet the delay and throughput requirements for RMMS traffic as specified in Appendix E. In particular, average end-to-end delay in peak hour from an Enroute MPS through NADIN to an Enroute MPS associated with the other NADIN switch including MPS processing time is:

- 2.31 seconds during FSAS and AWP file transfers, and

- 1.76 seconds during normal period.

This compares favorably with the 3 second average delay specified in Appendix E. The delays listed above are for foul weather conditions and so represent worst case behavior. The calculations and delay model are described in Appendix E.

4.2.2 Alternative 1 - Phase II Performance

Addition of the Phase II RMMS traffic will increase delays and throughput. However, service will remain within NADIN requirements for Scenario I, provided NADIN base traffic is still at the IA levels. Network delays have been computed for Phase II - Scenario I traffic but not for Phase II - Scenario II. For Phase II - Scenario II line utilization on the heaviest switch to concentrator link will be approximately .70. This makes significant delays a very real possibility if capacity remains unchanged. However, since new users are

very likely to be using the network by 1987 it is almost certain that backbone capacity will be increased. Hence delay calculations for Phase II - Scenario II would not be particularly meaningful and are not included. For other cases, NADIN network delays are shown in Table 4-2.

NADIN can provide adequate service to RMMS traffic in Phase II provided the enhancements in port speed and processor capacity discussed in Section 5 are carried out. The average delays expected for a typical RMMS message from Enroute MPS to NADIN concentrator to NADIN switch to NADIN switch to a NADIN concentrator to Enroute MPS are listed in Table 4-3 under various loads.

4.2.3 Long Term Performance

The long term impact of RMMS and the national Maintenance Management System on NADIN performance is difficult to quantify at this point in the development of these two nascent programs. However, it is apparent that additional backbone capacity will be needed by the 1990-92 time frame if the MMS is fully implemented. This additional capacity might be in the form of new NADIN backbone links for higher connectivity or increased band width on existing links.

4.2.4 Sensitivity to Change in Traffic Scenario

The scenarios on which these performance values are based were those projected by the RMMS program office at the time the study was undertaken. Changes in these scenarios are now a distinct possibility particularly in the local access arrangements for the RMS/MPS links. However, these changes to the RMMS configuration for Phase I and beyond do not impact the aggregate RMMS traffic to be carried by the NADIN backbone nor the aggregate locally switched traffic at the NADIN concentrator. The possible changes in RMMS configuration are outlined in Section D.5. The recommendations and findings in Section 5 remain valid although slight changes in the throughput/delay results for the Enroute MPS/NADIN link may occur under the possible new RMMS configuration.

ENVIRONMENT	FILE TRANSFER PERIOD	AVG. DELAY (SEC)	
		FULL FRAME MSG	RMMS MSG
NADIN IA	Y N	1.57 1.03	1.24 .7
Phase I	Y N	1.62 1.07	1.29 .74
Phase II, Scenario I	Y N	1.62 1.07	1.29 .74

TABLE 4-2: NADIN AVERAGE NETWORK DELAYS

	FILE TRANSFER PERIOD	E MPS/NADIN INTERFACE SPEED	
		2400 B/S	4800 B/S
Phase I	Y	2.31	-
	N	1.76	-
Phase II, Scenario I	Y	3.08	1.83
	N	2.53	1.28

TABLE 4-3: AVERAGE MPS TO MPS DELAYS: E MPS-NC-NS-NS-NC-E MPS

4.3 Comparison of Alternatives

The networking approaches defined in Section 3 are compared in several key areas including:

- effectiveness - meeting the initial communications needs of RMMS and MMS,
- efficiency - the efficient use of NADIN resources,
- timeliness - the ability to implement NADIN support in a time frame compatible with RMMS scheduling,
- RMMS futurity - the ability to provide for future communications support of RMMS, and
- NADIN futurity - the ability to integrate RMMS driven enhancements of NADIN with other planned or potential enhancements of NADIN.

These items are discussed in subsequent sections. A quantitative summary in table form of these and related factors is shown in Table 4-4.

4.3.1 Effectiveness for Initial Requirements

All four of the alternatives considered will meet the initial communications needs of MPS to MPS communications. However, if large file updates are common in Phase I (not expected) then Alternative 4 will provide substantially better performance than any of the other approaches with Alternative 2 providing the next best results. Alternative 4 substantially reduces overhead as well as reducing the average number of hops from origin to destination. Alternative 2 reduces overhead compared to Alternative 1 and also eliminates message processing at the switch (DS 714) as does Alternative 3.

FACTORS	ALT 1	ALT 2	ALT 3	ALT 4
NADIN Hardware Mods	8	6	5	2
NADIN Software Mods	8	6	6	2
RMMS Hardware Mods	8	7	7	6
RMMS Software Mods	5	5	9	6
Effective Commn.	4	7	7	9
Efficient Use of NADIN	2	7	6	9
Timeliness	9	7	8	1
RMMS Futurity	2	6	9	10
NADIN Futurity	4	6	6	10

Scale: 1 = highly unfavorable factor
10 = highly favorable factor

TABLE 4-4: COMPARISON OF ALTERNATIVES

4.3.2 Efficiency

This criterion sharply differentiates the alternatives. NADIN was designed initially to replace a variety of low-speed teletype circuits, primarily Area B. The network was conceived as a value added message switching system which would provide code and speed conversions as well as format editing and retrieval of accountable traffic for non-intelligent terminals. Alternative 1 is a continuation of this approach. However the MPSs which control RMMS and MMS are not teletypes; they are intelligent host computers as discussed in Section 2. MPS traffic does not require message processing at the message switch.

In Alternative 2 the concentrator does not need to look into the text of MPS messages and build a NADIN transport header. The message switch does not need to build the network address from the message address. Under Alternative 2 the MPS does all these things with no more effort on its part than message preparation in Alternative 1.

Alternative 3 requires the NADIN concentrator to build a transport header but it should be possible to construct the header primarily based on the MPS supplied packet header and implied information based on origin-destination. Hence Alternative 3 should reduce message processing at the NADIN concentrator.

Alternatives 2, 3 and 4 eliminate the need for message based processing of MPS messages by the DS 714s and reduce by at least one the number of hops for a typical frame. Of course those messages from teletypes and other sources which do require network services will continue to receive them at the NADIN switching centers as in NADIN IA.

4.3.3 Timeliness

The Enroute MPS installation plan (Reference 8) shows complete installation, testing and acceptance of all 23 Enroute MPSs (plus one at Oklahoma City) by calendar year 1984. Since NADIN IA is not scheduled for completion until the third quarter of calendar year 1983, it is important that additional delays to initiate NADIN support of MPS to MPS communication be kept to a minimum. It is this criterion which makes Alternative 4 infeasible for the short term. The modifications, both software and hardware (Section 4.1), needed to accomplish Alternative 4 are extensive, involving major delays and need for substantial additional funding. The costs for these enhancements are being addressed by NAC for the FAA under this contract, Task 13.

The minimum modification and hence the quickest implementation is possible under Alternative 1, since this is only a minor extension of the NADIN IA architecture, primarily in the enhanced local switching.

Alternative 2 would require more time to implement than Alternative 1 but involves no new hardware or communications links. The software changes are substantial at the concentrator and particularly the FEP but should not cause a major delay in integrating RMMS into NADIN.

Alternative 3 is very timely from the RMMS side. It will be easy to provide an X.25 interface for the MPSs since Tandem has an off-the-shelf X.25 package. However, the software to maintain correspondence between MPS initiated virtual circuits and network addressing of messages would be considerable. In addition, the FEP and some of the concentrator mods of Alternative 2 are also needed. Preliminary analysis shows Alternatives 2 and 3 are about equal here.

4.3.4 Futurity from RMMS/MMS Viewpoint

It is essential that RMMS and MMS communications needs for MPS-MPS traffic be met not only in the short run but also the long run. In the same vein NADIN planners want to ensure network users that their future, as well as their current needs, are being taken into account. From this perspective Alternative 4 is the superior approach. In the late 1980s it is expected that the Maintenance Management System will have reached a high level of development characterized by large file updates and file transfers. Interactive traffic will be common in RMMS by then. Hence the virtual circuit service possible in Alternative 4 will be of great benefit.

None of the other three alternatives will be suitable in the long term. However, they differ in the degree to which they hinder or aid the evolution of the MPS/NADIN system to Alternative 4. From the MPS side, Alternative 1 is a step in the wrong direction, i.e., away from packet switching and computer-to-computer communication. Software to segment files into 3700 character messages would be required at the MPS. Message headers would be inserted. Alternative 1 forces the MPS to emulate a dumb terminal which is not desirable either for NADIN or for the RMMS/MMS programs.

Alternative 2 is a partial step in the direction of Alternative 4. The MPS would hand frames to NADIN with their contents transparent to the network. NADIN handling would be frame based rather than message based. Long files would be packed into frames by the MPS just like any other MPS data.

Alternative 3 is obviously a major step toward the total packet switched approach of Alternative 4. From the RMMS side no further change is needed to achieve virtual circuit service. This is a very strong point for Alternative 3.

4.3.5 Futurity from the NADIN Viewpoint

It appears that by the late 1980s NADIN will evolve into a packet-switched network offering X.25 interfaces, virtual circuits and datagram service to users such as NAS-NAS (Computer B). The need for this evolution has been indicated in References 9 and 10 and it is expected that future user needs will add to this requirement.

In light of this trend, Alternative 4 is the approach with the most NADIN futurity. However, it is possible to measure the other three approaches against this criterion also.

Alternative 1 does nothing to advance the trend of NADIN to become more than a message-switched network designed for low-speed terminals.

Alternatives 2 and 3 make a small step toward making NADIN a network suitable for computer-to-computer communications. However the software changes for concentrator and FEP routing to accomplish Alternatives 2 and 3 are for the most part strictly interim measures and are not useable for the jump to Alternative 4.

In the near future it is almost certain that NADIN will be serving users who demand an X.25 interface. As more and more vendors provide off-the-shelf X.25 packages this demand will increase. In this crucial respect Alternative 3 takes an important step toward creating a packet-switched NADIN network responsive to future user needs.

4.3.6 Overall Comparison

The selected alternative must be effective, efficient, timely and provide futurity for both RMMS and NADIN. Based on the analysis above, Alternative 3 is overall the most feasible. Implementation schedules rule out Alternative 4 although for the long term it is the preferred approach. Alternative 1 is not appropriate for computer-to-computer communications and should only be recommended if time is so critical that no time is available for software mods at the concentrators and FEPs. Alternative 2 offers benefits in performance but lack of futurity weighs heavily against it. Table 4-4 shows a subjective assignment of weights based on the factors discussed in Section 4.3.

SECTION 5

RECOMMENDATIONS

5. INTRODUCTION

The recommended networking approach for NADIN support of RMMS is Alternative 3. This approach utilizes the current NADIN backbone and hardware configuration. Data is presented by the MPS to the network as packets across an X.25 interface.

The NADIN concentrator will interpret the packet header and for non-local traffic will build a NADIN transport header as in NADIN IA (Reference 5). Local traffic can be routed by the concentrator directly. Non-local traffic is forwarded to the FEP which is enhanced to perform routing. RMMS and MMS frames are routed by the FEP directly to their network exit point (concentrator) bypassing the message processor (DS 714) at the switching center. Other NADIN traffic will be routed to the message processor if necessary for accountability, editing, etc. The relation of protocol layers for NADIN IA is shown in Figure 5-1. The relation of protocol layers for the MPS-NADIN-MPS transfer of data is shown in Figure 5-2.

The enhancements to NADIN and the MPS/NADIN interfaces to implement this recommendation are discussed in this section.

5.1 Recommended NADIN Enhancements

The necessary extensions and modifications to NADIN are primarily in the FEP and concentrator software although ports at NADIN concentrators are also required. The requirements are:

- Concentrator Hardware and Software Modifications - to support X.25 physical, link and network layers and to provide local routing capability.

- FEP Software Modifications - to recognize MPS frames and perform routing of these frames based on concentrator supplied transport header.

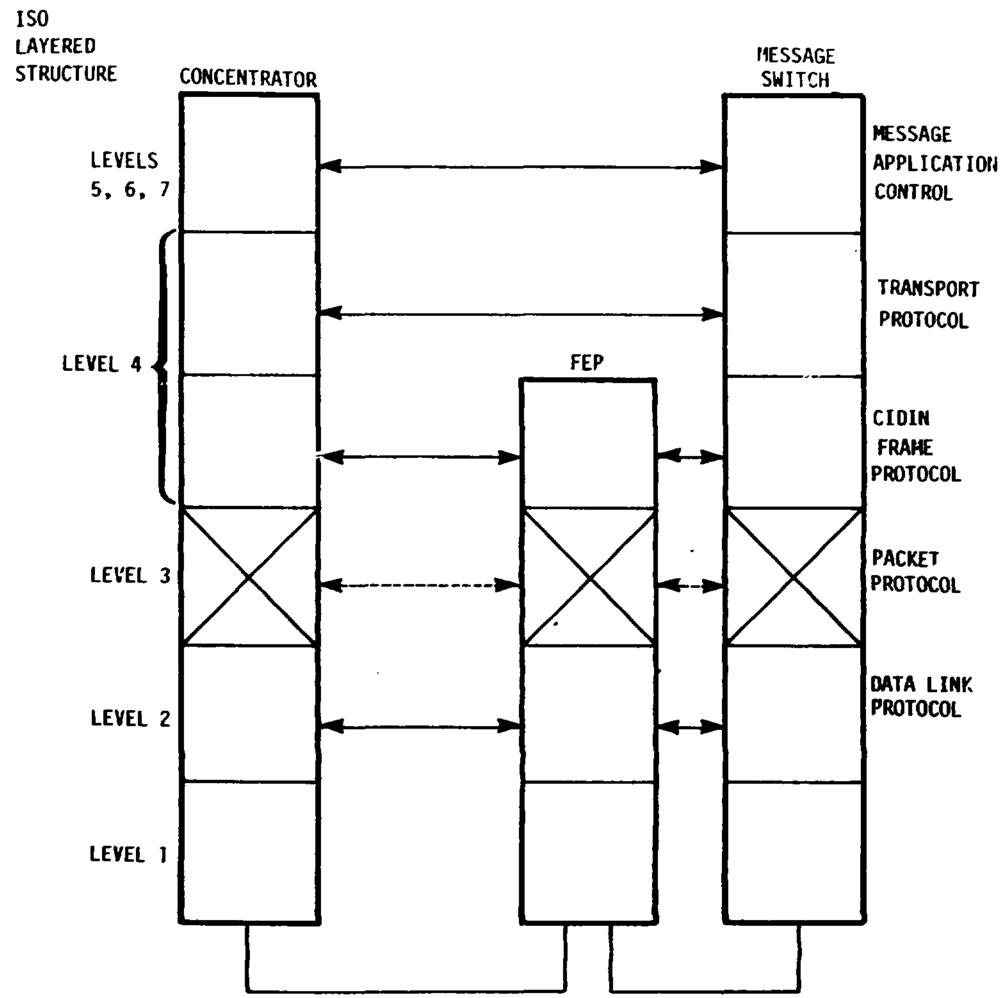


FIGURE 5-1: PROTOCOL LEVELS IN NADIN IA

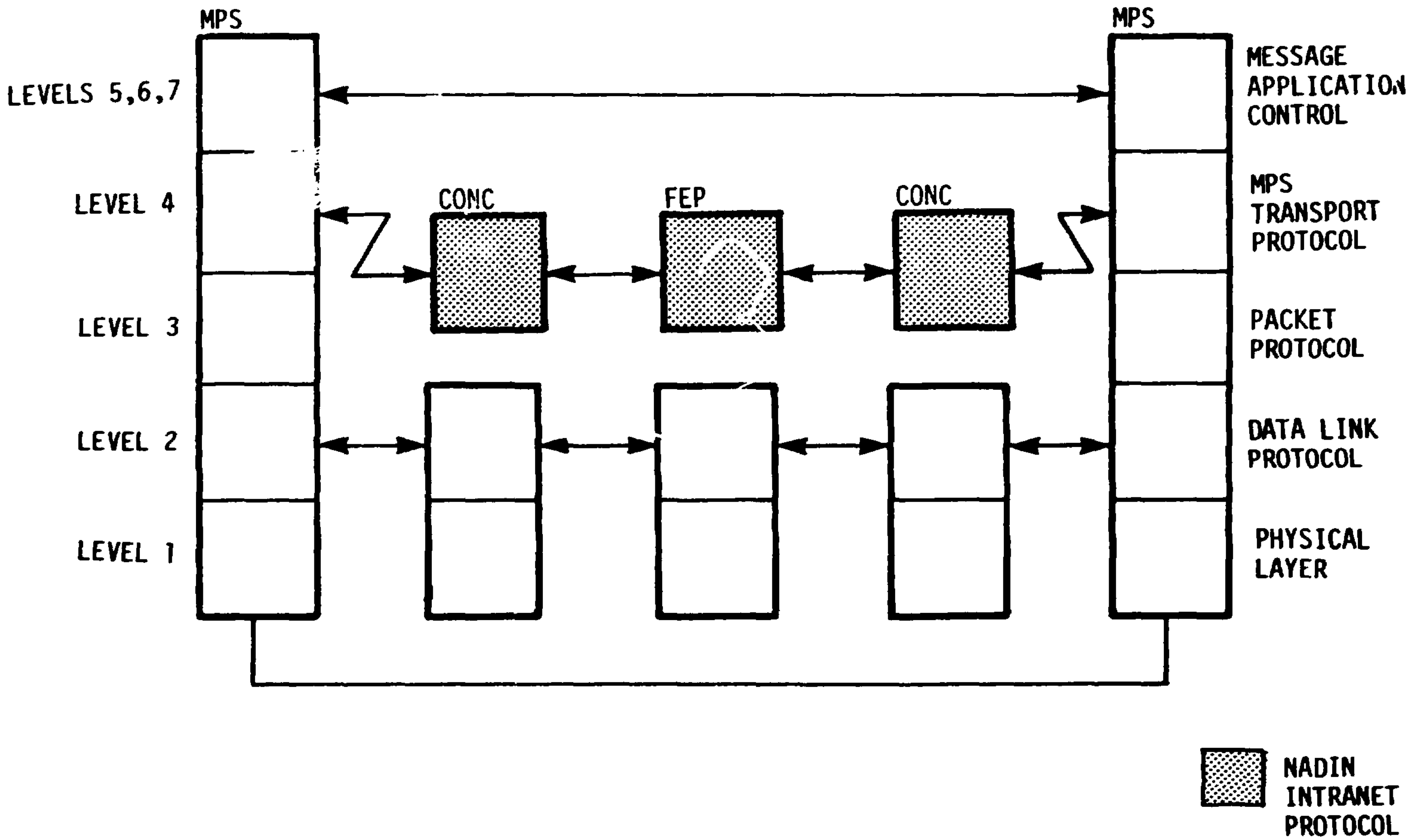


FIGURE 5-2: PROTOCOL LEVELS IN MPS-MPS COMMUNICATION

- Ports - initially (1982-3) one additional 2400 b/s port at each concentrator for Enroute MPS; later (1984-87) an average of four additional 2400 b/s ports at each concentrator for Sector MPS. Speeds will be upgraded as needed when significant numbers of additional RMSs come on line (after 1987).

5.2 MPS/NADIN Interface

The recommended interface includes levels one, two and three of the International Standards Organization (ISO) seven layer model (Figure 5-2). Level four is discussed but a detailed recommendation is not included for MPS to MPS level four protocol. The major features of the interface are summarized below. The details are presented in Appendix C: MPS/NADIN ICD.

5.2.1 Physical Layer (ISO Layer 1)

The Enroute MPS will be located in the ARTCC. The channel can be implemented in a direct DTE-to-DTE full duplex configuration per EIA RS-449 (balanced) standards. Limited distance modems may be used however. The communication facility will be twisted pair cables. Speed will be 2400 b/s.

The general NAS Sector MPSs are remote from the NADIN concentrator. They will be connected by full duplex leased lines (4 wire conditioned type 3002) and modems. Switchable modems capable of handling full duplex synchronous 2400 or 4800 b/s transmissions should be used with initial speed at 2400 b/s. The electrical/mechanical standard is again EIA RS-449 (balanced).

This physical layer is capable of supporting an X.25 interface to NADIN (Levels 2 and 3) without electrical modification. For open system interconnection via international common carriers X.25 calls for a somewhat different mechanical interface. However, the RS-449 mechanical interface is easily modified to be X.25 compatible.

5.2.2 Link Layer (ISO Layer 2)

The link level procedure will be ADCCP as described in Appendix C. Briefly this is a two-way simultaneous non-switched point-to-point bit oriented protocol. The Balanced Asynchronous (BA) Mode shall be used with each station acting as a combined (primary and

secondary) station. Bit stuffing and flags are used to achieve code and byte independent transmission. Cyclic Redundancy Checks (CRC) are used for error control. This protocol with the balanced mode and other specifications of the ICD is compatible with the CCITT LAPB protocol.

5.2.3 Network Layer (ISO Layer 3)

The X.25 packet layer or network layer is used for the exchange of packets between MPSs. The underlying NADIN network will not use X.25 internally (until such time in the future that NADIN evolves to a packet-switched network). The X.25 interface provides virtual circuits and datagram service to the MPS which NADIN must support with software modifications. NADIN internally uses a transport header for each frame. The NADIN transport header provides to NADIN some of the end-to-end transport functions such as correct sequencing of frames. This information must be stored by the NADIN exit point and passed across the X.25 interface to the MPS destination. Special software at the concentrators will be needed to make the conversions and supply the packet headers to the outbound RMMS packets/frames. In particular additional buffer capacity could be required to store frames for possible resequencing.

The transport layer (ISO Layer 4) for the MPS to MPS data transfer is not part of the ICD. This layer is discussed in Appendix G. Figure 5-3 shows the form of an MPS packet and the relationship of the various headers.

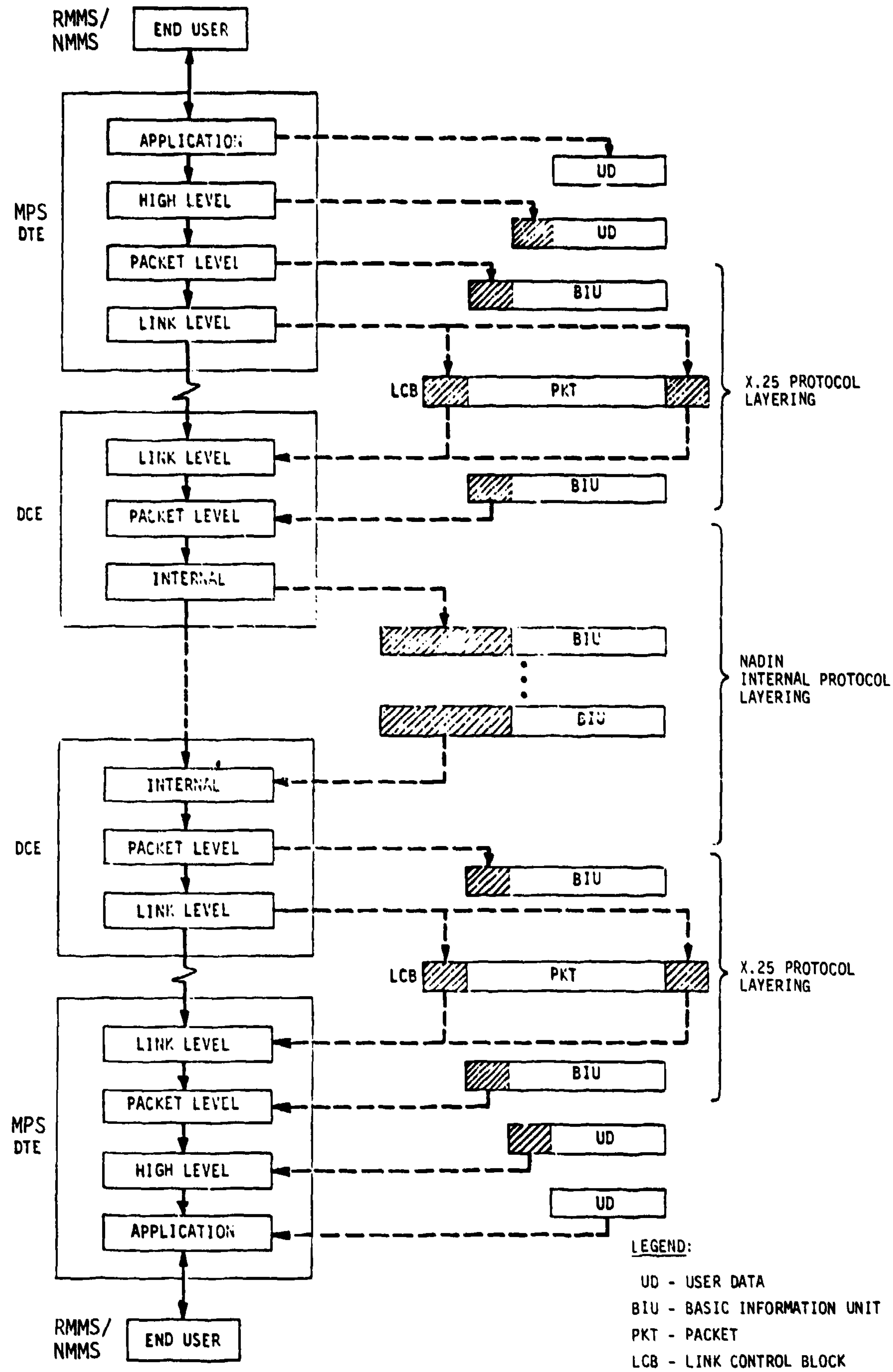


FIGURE 5-3: RELATIONSHIP OF HEADERS

APPENDIX A

RMMS OPERATION

RMMS operation is outlined below for Phase I and Phase II (Reference 8). The operational structure of RMMS and the type of NADIN support needed for each phase are specified.

A.1 RMMS PHASE I

Phase I of the Remote Maintenance Monitoring System consists of the enroute or center Maintenance Processor Subsystems (MPS), two Remote Monitoring Subsystems (RMSs) - Remote Center Air Ground (RCAG) RMS and Second Generation VORTAC RMS, the fixed terminals at work centers and technicians' portable terminals and those portions of the Telecommunications Network (TCN), including NADIN, required to service them. In this section the role to be played by NADIN in Phase I is discussed and the components of Phase I are defined.

A.1.1 MPS to MPS Communication in Phase I

The Enroute MPS in each enroute area will carry out certification reports, maintain parameter data and respond to alarm signals from the various RMSs. In addition, the Enroute MPS serves as the information source for the work center fixed terminals and to some extent for the portable terminals. In particular, facility alarms are forwarded by an Enroute MPS to the responsible work center and its associated Sector Office. Herein lies the first major need for inter-area MPS to MPS communication.

Many of the approximately 80 Airway Facility Sectors include portions of two or more Air Traffic (AT) enroute areas. Therefore, a facility such as an RCAG or VORTAC lies in one AT enroute area while the Sector Office for that AF sector is located in an adjacent AT enroute area. The work center responsible for the facility would typically be in the same enroute area as the facility site but even this may not always be the case. Hence, it is necessary for alarms and other information originating at or destined to a facility RMS to

pass from one Enroute MPS to another adjacent Enroute MPS. It is planned (Reference 7) that NADIN will perform this communication function. Figure A-1 illustrates the overlapping sector phenomenon as well as the NADIN interconnection for MPS to MPS traffic. Table A-1, based on data in Reference 18, lists the work centers which under current sector boundaries will report to Sector Offices outside the work center's enroute area.

A.1.2 Data Base Locations in Phase I RMMS

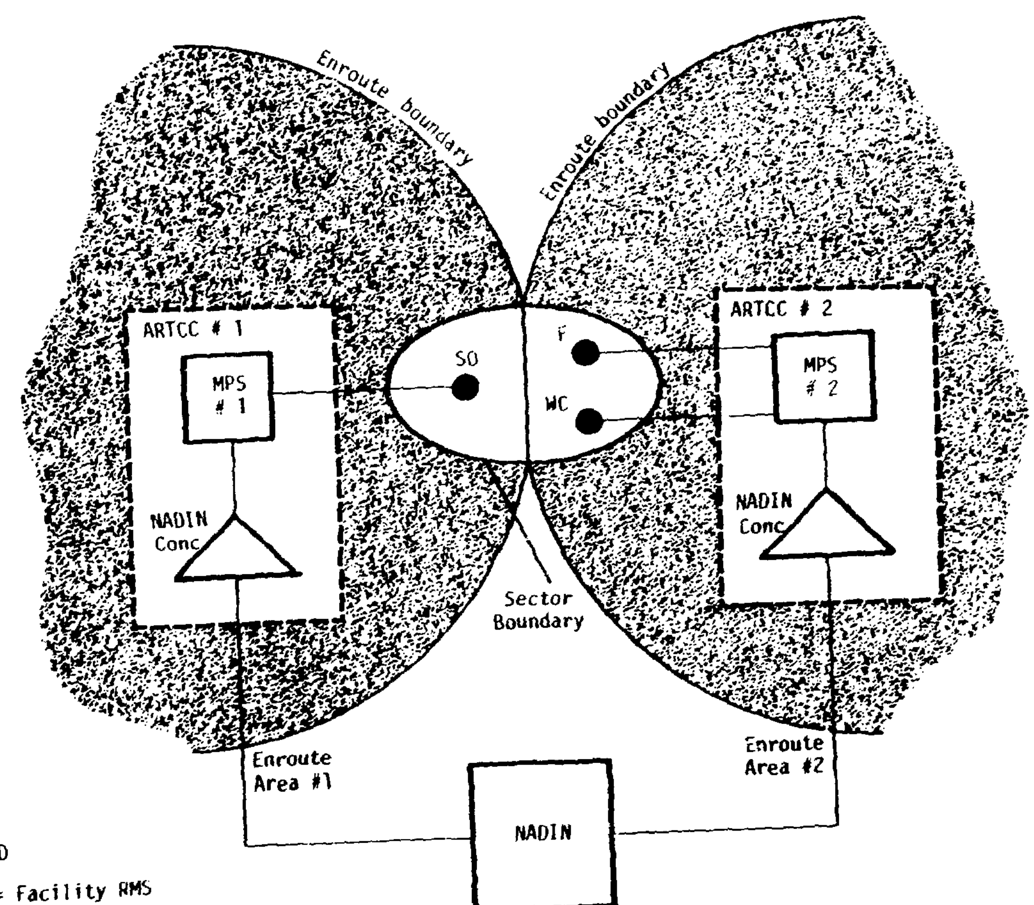
Each Enroute MPS will maintain status, alarm, certification and other data on each of the RMS monitored facilities and work centers within its enroute area's boundary. In addition, each MPS will maintain a copy of the data concerning any facilities or work centers which are located in an adjacent enroute area but are associated with a Sector Office in the given MPS's area. Referring to Figure A-1, both "MPS #1" and "MPS #2" will maintain essentially identical files of Facility "F" data. Inquiries from the Sector Office concerning Facility "F" in Figure A-1 would normally be answered by MPS #1 from its Facility "F" data without the need to go back to MPS #2.

A.1.3 Regional and National Data Access in Phase I

Headquarters Washington, Regional Headquarters, National Support Group and possibly others will from time to time require access to data at Enroute MPSs. In Phase I RMMS, they will access this data via a dial-up connection either through FTS or the public network but not via NADIN. This is one of the features that distinguishes Phase I implementation from Phase II in which such access to local data bases will be via NADIN.

A.2 RMMS Phase II

Phase II of RMMS is defined precisely in Section 2.3. It includes, in addition to Phase I, the approximately 80 General NAS Sector MPSs, some features of the Maintenance Management System, and the candidate RMSs described in Section 2.3.3 such as ARSR, RML, ASR and others.



LEGEND

F = Facility RMS

WC = Work Center Terminal

SO = Sector Office

FIGURE A-1: OVERLAPPING SECTOR

WC ENROUTE AREA	WORK CENTER	SECTOR OFFICE	SO ENROUTE AREA
Atlanta	Charlotte, NC (CLT)	Raleigh/Durham, NC (RDU)	Washington
Atlanta	Columbus, GA (CSG)	Savannah, GA (SAV)	Jacksonville
Chicago	Waterloo, IA (ALO)	Des Moines, IA (DSM)	Minneapolis
Chicago	Kalamazoo, MI (AZO)	Grand Rapids, MI (GRR)	Cleveland
Cleveland	Clarksburg, WV (CKB)	Charleston, WV (CRW)	Indianapolis
Denver	Goodland, KS (GLD)	Wichita, KS (ICT)	Kansas City
Ft. Worth	Waco, TX (ACT)	Austin, TX (AUS)	Houston
Ft. Worth	San Angelo, TX (SJT)	Austin, TX (AUS)	Houston
Ft. Worth	Texarkana, AR (TXK)	Little Rock, AR (LIT)	Memphis
Houston	Gulfport, MS (GPT)	Montgomery, AL (MGM)	Atlanta
Houston	Hattiesburg, MS (HBG)	Jackson, MS (JAN)	Memphis
Indianapolis	Evansville, IN (EVV)	Springfield, IL (SPI)	Kansas City
Jacksonville	N. Myrtle Beach, SC (CRE)	Raleigh/Durham, NC (RDU)	Washington
Kansas City	Clinton, OK (CSM)	Oklahoma City, OK (OKC)	Ft. Worth
Memphis	Owensboro, KY (OWB)	Covington, OH (CVG)	Indianapolis
Minneapolis	Duluth, MN (DLH)	Green Bay, WI (GRB)	Chicago
New York	Oneonta, NY (N66)	Albany, NY (ALB)	Boston
Salt Lake City	Wells, NV (LWL)	Reno, NV (RNO)	Oakland
Salt Lake City	Elko, NV (EKO)	Reno, NV (RNO)	Oakland
Seattle	Montague, CA (SIY)	Red Bluff, CA (RBL)	Oakland

TABLE A-1: WORK CENTERS WITH SECTOR OFFICE IN ADJACENT ENROUTE AREA

A.2.1 Location of Data Bases in Phase II

One of the main features of the Maintenance Management Subsystem and Phase II of RMMS in general is the maintenance of a distributed data base. National, regional and sector levels will all have corresponding data levels. The creation of one or more national Maintenance Management processors as well as possible locations have not yet been determined at this writing. However, it is planned that the national data base will contain summary information, trend analysis, logistics and training data, trouble shooting data and other material useful for national planning and management.

Each AF region will contain a regional Maintenance Processor Subsystem which probably will be a designated Enroute MPS although this decision is not yet finalized. The regional MPS will collect and store data relevant to that region's operation. Examples are regional summaries of equipment performance, modification records, trouble shooting data, equipment inventory, logistics inventory and others. This regional data is available to the national MMS for concatenation into national summaries.

The 80 General NAS Sector MPSs or possibly the Enroute MPSs will be responsible for storage of all data related to the individual RMS facilities, work centers and personnel in their sectors. Certification reports, alarm reports, actions taken in response to alarms, outage records, watch schedules and other data, especially that required on a day-to-day basis at the sector central maintenance facility level, will be stored locally. It is this local data from the various sector MPSs which the regional MPS uses to compile regional files which in turn are used for national analysis by the national MMS.

A.2.2 Role of the Enroute MPS in Phase II

Original plans for Phase II of the RMMS called for the Enroute MPS located at each ARTCC to be the hub of all monitoring, alarm notification and system interconnection. All certification reports, alarms, status messages and uplink commands were to be processed at the Enroute MPS. This plan has been modified. Current plans are for the Sector MPS to act as the hub for most but not all monitoring and alarm notification in its sector. Notification of alarms are sent by the Enroute MPS or Sector MPS to responsible technicians at a work center. In addition, notice of the alarm is also sent by the responsible MPS to the Sector MPS or Enroute MPS in whose boundary the alarmed facility is located, even when in some cases this Sector Office or ARTCC may be in an adjacent enroute area.

A.2.3 Data Access and Addressing Responsibility in Phase II

One of the major objectives of the national MMS program is to provide access for national, regional, sector and local technicians' terminals to any required RMMS data. Balancing this objective is the requirement to conserve communication costs and protect the system from overloading and abuse. Therefore, a hierarchical access is planned. This means that data requests should be satisfied routinely by the data base logically nearest to the requesting level.

A request originating at National Headquarters will normally be satisfied by query of the national MMS data bases, similarly for regional requests and so on. A local technician, for example, will request information on a facility's status or repair record from his Sector MPS through the Enroute MPS. Access to data beyond a requestor's logical level or physical sector is to be handled in the following manner. First, availability of data to an individual will be regulated by the authorization level of that individual and/or terminal. Secondly, assuming proper authorization, a requestor may obtain data from a remote site in two ways. The requestor may simply forward his request to the appropriate Enroute MPS (via NADIN if this MPS is outside his area). The Enroute MPS will accept the request and solicit the requested information from the appropriate data location, typically a Sector MPS. This data will be what is currently available and will not result in facility polling. Alternatively, the requestor may supply the complete address of the remote site to NADIN which will pass it through the appropriate Enroute MPS for forwarding to the remote RMS. In this way the requestor can obtain essentially real time data rather than the currently available report stored in the Sector MPS.

APPENDIX B

RMMS FACILITIES (PHASE I)

B.1 Phase I Environment

Terminals, processors, monitoring subsystems and their associated circuits in Phase I RMMS are described in this section.

B.1.1 Enroute MPS

Program plans (Reference 8) call for delivery of twenty four (plus one optional) Enroute MPSs to be located at the twenty three Air Route Traffic Control Centers plus Oklahoma City with an option for Atlantic City. Delivery begins January 1982 and will be completed December, 1983 as shown in Table B-1. Testing of the processors is to be completed as of March, 1984.

In Phase I Enroute MPSs will interface with:

- RCAG RMS Type I and Type II,
- VORTAC Remote Monitoring Equipment (plans for using RMC-C at ARTCC have been dropped)
- work center fixed terminal output subnet
- portable terminals via dial up
- NADIN concentrator collocated at each center, and
- Flight Service Data Processing System (FSDPS).

DELIVERY NUMBER	SITE	DELIVERY DATE	TEST COMPLETION DATE
1	Site 1 Oklahoma City**	1 Jan 1982	9 Apr 1982
2	Site 2 Kansas City	22 Feb 1982	21 May 1982
3	Site 3 Los Angeles	5 Apr 1982	2 Jul 1982
4	Site 4 Anchorage	10 May 1982	13 Aug 1982
5	Site 5 Chicago	21 Jun 1982	24 Sep 1982
6	Site 6 Atlanta	9 Aug 1982	5 Nov 1982
7	Site 7 Fort Worth	6 Sep 1982	3 Dec 1982
8	Site 8 San Juan	11 Oct 1982	7 Jan 1983
9	Site 9 Houston	8 Nov 1982	4 Feb 1983
10	Site 10 Jacksonville	6 Dec 1982	4 Mar 1983
11	Site 11 Albuquerque	3 Jan 1983	1 Apr 1983
12	Site 12 Miami	31 Jan 1983	29 Apr 1983
13	Site 13 Oakland	28 Feb 1983	27 May 1983
14	Site 14 Memphis	21 Mar 1983	24 Jun 1983
15	Site 15 Seattle	25 Apr 1983	22 Jul 1983
16	Site 16 Honolulu	23 May 1983	19 Aug 1983
17	Site 17 Salt Lake	13 Jun 1983	16 Sep 1983
18	Site 18 Denver	18 Jul 1983	14 Oct 1983
19	Site 19 Indianapolis	15 Aug 1983	11 Nov 1983
20	Site 20 Minneapolis	12 Sep 1983	9 Dec 1983
21	Site 21 Cleveland	10 Oct 1983	6 Jan 1984
22	Site 22 Washington	7 Nov 1983	3 Feb 1984
23	Site 23 New York	5 Dec 1983	3 Mar 1984
24	Site 24 Boston*	26 Dec 1983	31 Mar 1984
25	Option Atlantic City		TBD

* Factory Test unit reinstalled

** Tandem equipment delivery dates to be three months earlier

Source: Reference 8

TABLE B-1: ENROUTE MPS DELIVERY SCHEDULE

Of these interfaces, those that have been defined are:

- RCAG RMS Type I and II - 110 bit/sec 4 wire half duplex data over voice using American National Standards Institute (ANSI) X 3.28 point-to-point subcategory 2.5 alternate two way link protocol (References 1 and 16),

- VORTAC - 1200 b/s data transmission using a speech plus data arrangement over voice grade lines with Advanced Data Communications Control Procedure (ADCCP) link protocol (References 1 and 19), and

- Work center output subnet - where needed medium speed connections using ADCCP link protocol (access arrangements are still under design). Other sites will utilize 300 b/s dial-up access.

The NADIN/RMMS interface is addressed in this report (Sections 2 and 5 and Appendix H).

B.1.2 RCAG RMS Units

There will be a total of 414 RCAG RMS units in Phase I including Type I and Type II scattered through 23 enroute areas. An additional 117 RCAG RMSs are expected to be added, bringing the total to approximately 531. Each Type II RCAG is collocated at an ARTCC with an Enroute MPS. Up to 40 Type I RCAGs feed into a Type II unit where voice is stripped and data passed to the MPS. Each Type I unit corresponds to a separate output port at the MPS to the Type II unit (Reference 2). Polling of Type I and II units is carried out by the Enroute MPS. Implementation is scheduled over the period 1982-1983 as shown in Table B-2. Each RCAG Type I and II is connected to the MPS via point-to-point links as described in Section B.1.1.

B.1.3 VORTAC RMS Equipment

There are approximately 906 Facility Central Processing Units (FCPUs) located at sites which contain VOR, TACAN, DME and support equipment. The FCPU polls equipment monitors which obtain parameter values measuring the conditions of the VOR, TACAN and DME equipment as well as environmental data. The FCPUs' local access to the Enroute MPS is now under revision. At some field locations such as Sector Offices in the busiest sectors,

the FCPUs may be polled and controlled by a communication controller device which will interface via leased lines or possibly dial-up to the Enroute MPS or eventually the Sector MPS. At less busy locations the FCPUs may utilize dial-up connections direct to the Enroute and/or Sector MPS to report alarm conditions. Certification action at such sites would be initiated by dial-out from the MPS. These issues are still under study by FAA at this time. As shown in Table B-2, implementation of the second generation VORTAC equipment is scheduled to occur incrementally over the period 1981 to 1984.

B.1.4 Terminals

Phase I RMMS utilizes both fixed and portable terminals. Fixed terminals will be located at 240 work centers (WC). Examples of least cost circuit configurations for leased lines are shown in Reference 18. These fixed terminals will form a subnetwork, some of which will utilize 2400 bit/sec multipoint lines using a four wire full duplex mode with an ADCCP link protocol. Other WCs will use dial-up to the MPS. The Enroute MPS will maintain a list of work centers responsible for each monitored facility. When an alarm occurs, these responsible technicians will be notified via the fixed terminal output subnet.

Portable terminals will be provided to technicians travelling to remote sites for maintenance or inspection. These terminals can be used in two different modes. First a terminal can be connected on-site to query the local RMS directly for status and parameter information. However, if further information is needed or if data about a remote site is required then the portable terminal can access the Enroute MPS via a dial up connection. The number of portable terminals on line at any given time should strongly correlate with on-site trips by service technicians. The traffic generated by these visits is discussed in Appendix C.

Washington Headquarters, Regional Headquarters and possibly other locations will be equipped with terminals which can access data at Enroute MPSs via dial up connection. The precise number of these terminals has not yet been determined and many may not be implemented until Phase II.

COMMISSIONING

RMMS COMMISSIONING SCHEDULE
(1981-1984)

Year	Numbers of RMS Units						RCAG	MPS at ARTCC
	VOR		VORTAC		ARSR			
	Single	Dual	Single	Dual	LRR	ATCBI		
1981	-	-	81	81	-	-	-	-
1982	-	-	144	144	-	-	116	6
1983	50	20	109	109	-	20	298	13
1984	73	55	-	-	23	-	-	4
TOTALS	123	75	354	354	23	20	414	23

Source: Reference 8

TABLE B-2: RMMS COMMISSIONING SCHEDULE

APPENDIX C

RMMS TRAFFIC

The heart of a data communications requirements analysis is the compilation of the traffic loading which must be served by the utility. In this appendix, the message types, their length characteristics, arrival characteristics, their sources, sinks and other essential features are discussed. Traffic is described in detail for Phase I. However, Phase II RMMS traffic is expected to consist of the same message types.

C.1 MESSAGE TYPES

The RMMS will transmit 17 types of messages which will require NADIN handling in Phase I. These are discussed briefly below grouped into four message categories.

C.1.1 Alarm Messages

Whenever an alarm condition is detected by an RMS and after appropriate pre-alarm filtering, an alarm message is forwarded to the Enroute MPS. A notification is then sent by the MPS to the responsible work center and appropriate Sector Offices provided the time of day is a manned period for that office. When the alarm condition is corrected, the work center notifies the Enroute MPS. However, if the MPS itself notes that the alarm condition no longer exists, it will notify the appropriate work centers or other terminals. Altogether the alarm process involves a total of five message types:

Alarm Message (AM) - notification that particular parameter at indicated site has exceeded alarm threshold.

Alarm End (AE) - notification by MPS to appropriate terminals that alarm condition no longer exists.

Alarm Delete (AD) - notification by technician that alarm condition has been corrected.

Alarm Disable (DA) - request by technician or responsible Sector Office to MPS advising that particular alarms are to be ignored.

Alarm Threshold Change (TC) - request by authorized personnel that MPS temporarily change RMS alarm threshold.

C.1.2 Certification

Service certification will be accomplished by the MPS on a scheduled basis or as requested by authorized technicians. This certification will involve the comparing of "certification parameters" received from the RMS with specified parameter values. This process will become a major part of the legal certification process but will not replace human decision authority. The three message types associated with certification are:

Certification Report (CR) - Response by RMS to a scheduled poll requesting full or partial certification data. These messages employ highly structured format (References 1, 16, 19 and 20) to achieve data compression.

Certification Request (CQ) - Request by MPS for certification data from RMS. Varies with type of RMS, i.e., RCAG vs. VORTAC.

Certification History (CH) - Information from previous certification reports and/or the logging data concerning the collection of those reports.

Certification History Request (CHQ) - Request for information from previous certification reports and/or data concerning collection of these reports.

C.1.3 Status Messages

The Remote Monitoring Subsystem status message provides information on the condition of the RMS and its peripherals. Such messages can be generated in response to requests from the MPS, from Airway Facilities personnel via terminals or in the case of VORTAC RMS, automatically in response to a continuous poll when the system detects a problem with itself. The level of detail in the status report will vary depending on the type

of RMS and on the method of generation. In Phase I RMMS there are six types of messages associated with status reporting:

VORTAC Status Condition (VSC) - Brief synopsis of status condition in each of four monitor elements; VOR, TACAN, DME and environmental in response to continuous polling.

VORTAC Status Reply (VSR) - Listing of all parameter values associated with requested monitor(s). Single parameter values can not be obtained except with entire set of monitor's data.

VORTAC Status Request (VSQ) - Uplink servo command to one or more of the four VORTAC elements for status report.

RCAG Status Reply (RSR) - Report of single parameter or group of parameters in response to request by MPS or by locally connected technician.

RCAG Status Summary (RSQ) - Uplink command by MPS to send one or more parameters of one or more RCAG subelements (channels, etc.), usually generated by MPS in response to an alarm notification.

RCAG Status Summary (RSS) - Summary of equipment status as currently stored at MPS.

C.1.4 Terminal Messages

In addition to the message types mentioned above, technicians may input and exchange free format English language messages via fixed or portable terminals.

Teletype or Free-Format Messages (TTY) - Messages in free format English to or from a terminal.

C.1.5 Miscellaneous Messages

Occasionally other messages will be transmitted in the RMMS. These shall be collectively referred to as:

Administrative Messages (ADM) - Generally related to network operation or simply general information.

C.2 MESSAGE CHARACTERISTICS

In this section, message lengths and frequencies are discussed for Phase I RMMS. The figures presented represent best estimates based on current implementation philosophy as outlined in References 1, 2, 7, 8, 19 and 20. In addition, interpretations and verbal updates from AAF 450 personnel have been reflected. Precise values will probably change as implementation proceeds. However, for initial design purposes the values contained in this section are sufficiently firm.

C.2.1 Message Lengths

The lengths of the various messages discussed in Section C.1 are shown in Table C-1. Since most of these message formats have not yet been completely specified between RMS and MPS the lengths shown for MPS to MPS traffic represent best estimates. In particular, certification report formats have not been finalized at this writing by the RMMS program. Various block sizes are being considered especially for the scheduled certification reports with an eye to prevent the longer but lower priority certification message from delaying short but high priority alarm and status messages. The certification report (CR) length shown in Table C-1 is the entire message not a single block of the certification report. That is, the CR includes the parameter values for all subelements, e.g., channels, environmental and common at an RCAG. The individual parameter groups will be transmitted from RMS to MPS as blocks of an as yet undetermined size and may even be treated by the lowest three protocol layers as separate messages. But the MPS will treat these parameter group blocks as part of the same certification report. It is on this basis that certification reports and related messages are sized in Table C-1.

TYPE	COMMENTS	AVG (CHAR)	MIN	MAX
VOR AM		30	20	90
RCAG AM		18	16	20
VOR AE		30	20	90
RCAG AE		20	16	40
VOR DA		25	20	90
RCAG DA		25	20	40
TC		25	20	40/90
VOR CR	Multiple blocks	600	450	700
RCAG CR	1) Type I RCAG only 2) Multiple blocks	400	200	600
VOR CH	2 CRs plus logs	1,300	1,000	1,500
RCAG CH	2 CRs plus logs	900	500	1,300
CHQ		30	25	90
VSC		12	12	12
VSR	avg = one monitor	100	70	700
VSQ		25	20	30
RSR		70	36	1,000
RSQ		16	12	30
FFM		80	20	1,000
ADM		120	30	1,500

TABLE C-1: MESSAGE LENGTHS

One assumption regarding the contents of certification reports is made. It is assumed that alarm threshold levels are to be included and may vary with each occurence of that parameter at a different subelement. For example, Channel 1 and Channel 2 at an RCAG facility may have different alarm thresholds specified which will both be reported in the certification report.

C.2.2 Message Frequency

Traffic load in RMMS Phase I from MPS to MPS which is to be supported by NADIN is presented in this section. Tables C-2 and C-3 show the heaviest loading projected for a NADIN concentrator due to MPS traffic for normal and extreme foul weather respectively. These estimates are based on RCAG and VORTAC Specifications (References 7, 17 and 18) plus discussions with program personnel. The concentrator load consists of the sum of all RMMS traffic to or from the collocated Enroute MPS. Several steps are used to derive the results in Tables C-2 and C-3:

- the traffic is assumed uniform for each type of facility, i.e., each 6 channel RCAG, etc.,

- to obtain an upper bound on traffic, the number of facilities per work center is assumed equal to twice the average, i.e., 6 RCAG RMS and 8 VORTAC RMS per work center.

- the maximum traffic occurs at concentrators in the ZHU and ZFW areas, each of which have a combined total of four work centers which exchange information with remote Sector Offices.

Of this data, the greatest uncertainty relates of course to the frequency of alarm occurences. Since in many cases the equipment being monitored will be new solid state hardware, the predicted alarm rates are subject to revision as experience with the system is acquired.

To compute maximum one direction link flow due to Phase I RMMS from MPS to NADIN concentrator or reverse, the total node traffic shown in Tables C-2 and C-3 is multiplied by the factor L = 0.75.

TYPE	MSG/HR	KB/SEC	COMMENTS
RCAG CR	24	.02	
VORTAC CR	32	.044	Assumes all VORTAC certifications in same hour
RCAG AM	1/4	.00001	Based on one alarm/site/4 days
VORTAC AM	1/5	.000014	One alarm/site/week
RCAG AE	1/4	.000012	
VOR AE	1/5	.000014	
VOR DA	1/5	.000012	
RCAG DA	1/4	.000014	
TC	2/5	.000024	
VOR CH	1/30	.0001	once/month
RCAG CH	1/25	.00008	once/month
CHQ	2/27	.000006	
VSR	1/5	.00006	
VSQ	1/5	.000012	
RSR	1/4	.00004	
RSQ	1/4	.00001	
FFM	2/13	.00004	Assume 30% of alarms result in site visit
ADM	2	.0006	
TOTAL		.065	

TABLE C-2: MAXIMUM NORMAL RMMS TRAFFIC AT NADIN CONCENTRATOR (PHASE I)

TYPE	MSG/HR	KB/SEC	COMMENT
RCAG CR	24	.02	
VORTAC CR	32	.044	
RCAG AM	48	.002	2 alarms/site/hour
VORTAC AM	64	.006	2 alarms/site/hour
RCAG AE	48	.002	
VOR AE	64	.004	
VOR DA	64	.004	
RCAG DA	48	.004	
TC	2	.0002	
VOR CH	1/30	.0002	
RCAG CH	1/25	.0002	
CHQ	2/27	.000002	
VSR	64	.014	
VSQ	64	.004	
RSR	48	.008	
RSQ	48	.002	
FFM	56	.01	One visit/site/hour
ADM	14	.004	
TOTAL		.130	

TABLE C-3: FOUL WEATHER RMMS TRAFFIC AT NADIN CONCENTRATOR (PHASE I)

APPENDIX D

GROSS THROUGHPUT

Gross throughputs are calculated in this appendix both for the NADIN backbone links and for the RMMS/NADIN interfaces. Traffic levels are developed for four periods:

- NADIN Level IA - based on the net throughput contained in Table Z-9, Appendix Z of the NADIN Specification (Reference 4).
- Phase I RMMS plus NADIN IA - based on the net throughput for Phase I RMMS described in Appendix C.
- Phase II Scenario I RMMS - described in Section D.4.
- Phase II Scenario II RMMS - described in Section D.4.

D.1 GROSS THROUGHPUT MODEL

Peak-period throughput requirements, measured in bits per second (b/s), have been determined for each link. The requirements have been calculated in two forms:

- Net throughput (NT) - the bits representing original messages that are to be transmitted per second, and
- Gross throughput (GT) - the total number of bits, including all overhead transmissions, that are to be transmitted per second.

Both requirements are calculated from the average message length (L, measured in characters per message) and the peak-period message frequency (F, measured in messages per hour). Net throughput is the product of these two message characteristics, with appropriate conversion of units, i.e.:

$$NT = F \times L \times B/S$$

where $B = 8 =$ the number of bits per character,

$S = 3600 =$ the number of seconds per hour.

Thus:

$$NT = .002222 \times F \times L$$

Gross throughput reflects the addition of all other bit, character and message transmissions required by the network (NADIN) or link (ADCCP) protocols. These have been detailed in the Level IA Study (Reference 13) and are summarized below:

- NADIN requires a header and trailer on each "message". Together these involve approximately 63 characters. A NADIN message is limited to 3700 characters. Thus, any actual message or file which contains more than 3700 characters must be broken down into two or more NADIN messages, with a header and trailer added to each.

- Messages are transmitted across the individual NADIN backbone links in frames with 245 or fewer characters. ADCCP adds frame control data, equivalent to 11 characters for each frame, and inserts additional zero bits to avoid ambiguity between data and synchronization bit strings. It has been determined that the zero insertion process increases the number of bits (and hence the number of equivalent characters) by about 1.6 percent.

- Both the network and link protocols transmit control messages on the lines. It has been estimated that each adds the equivalent of 3 percent to the transmissions.

- Finally, the control procedures cause the automatic retransmission of frames containing transmission errors. It has been conservatively estimated that 2.5 percent of all frames must be retransmitted.

Taking these overhead items into consideration, the gross message length (GL) and gross message frequency (GF) are determined from:

$$GL = \left[L + (a \times 63) + (b \times 11)\right] \times 1.016$$

where a = the smallest integer $\geq$ L/3700,
b = the smallest integer $\geq \left[L + (a \times 63)\right]/245$.

$$GF = F \times 1.03 \times 1.03 \times 1.025$$

$$= 1.087 \times F.$$

The gross throughput is calculated as:

$$GT = GF \times GL \times B/S$$

$$= .00245\ F \times \left[L + (a \times 63) + (b \times 11)\right]$$

The message characteristics and associated throughput requirements for the four stages considered are presented in the following sections.

D.2 NADIN IA TRAFFIC

The traffic shown in Table Z-9 of the NADIN Specifications (Reference 4) is net traffic. These figures are used together with the overhead model from Section D.1 to derive the throughput shown in Tables D-1 through D-4. This is the NADIN IA base traffic to which the various RMMS increments are added in Phase I and Phase II.

D.3 PHASE I RMMS PLUS NADIN IA TRAFFIC

Phase I RMMS traffic (Table C-3) between Enroute MPSs will be carried by NADIN. The sum of this traffic plus the NADIN IA base traffic is shown in Table D-5. The RMMS gross throughput is based on the link and message overheads for the Alternative 1 Architecture described in Section 3. The model in Section D.1 applies under this assumption.

MESSAGE CHARACTERISTICS				PEAK THROUGHPUT (B/S)	
MSG TYPE	ACCOUNT	MSG/HR	MEAN CHAR	NET	GROSS
I	N	24	50	8	8
II	N	4,890	120	1,304	2,344
II	Y	1,101	120	296	528
III	N	14	3,000	96	112
IV	N	6	90,000	1,232	1,448
V	N	459	15	16	104
TOTALS		6,494		2,952	4,544

TABLE D-1: NADIN IA SWITCH TO CONCENTRATOR PEAK PERIOD TRAFFIC (WITHOUT RMMS)

MESSAGE CHARACTERISTICS				PEAK THROUGHPUT (B/S)	
MSG TYPE	ACCOUNT	MSG/HR	MEAN CHAR	NET	GROSS
I	N	840	50	96	256
II	Y	1,120	120	304	536
II	N	90	120	24	48
V	N	459	15	16	104
TOTALS		2,509		440	944

TABLE D-2: NADIN IA CONCENTRATOR TO SWITCH PEAK PERIOD TRAFFIC (WITHOUT RMMS)

MESSAGE CHARACTERISTICS				PEAK THROUGHPUT (B/S)	
MSG TYPE	ACCOUNT	MSG/HR	MEAN CHAR	NET	GROSS
II	N	324	120	88	160
II	Y	2,355	120	632	1,128
III	N	90	3,000	616	728
IV	N	6	90,000	1,104	1,448
TOTALS		2,775		2,440	3,464

TABLE D-3: NADIN IA ATLANTA SWITCH TO SALT LAKE CITY SWITCH PEAK PERIOD TRAFFIC (WITHOUT RMMS)

MESSAGE CHARACTERISTICS				PEAK THROUGHPUT (B/S)	
MSG TYPE	ACCOUNT	MSG/HR	MEAN CHAR	NET	GROSS
I	N	2,520	50	280	768
II	N	664	120	176	320
II	Y	2,355	120	632	1,128
IV	N	1	90,000	152	184
TOTALS		5,540		1,240	2,400

TABLE D-4: NADIN IA SALT LAKE CITY SWITCH TO ATLANTA SWITCH PEAK PERIOD TRAFFIC (WITHOUT RMMS)

LINK			PEAK THROUGHPUT	
FROM	TO	MSG/HR	NET BIT/SEC	GROSS BIT/SEC
Switch	Concentrator	7,694	3,056	4,872
Concentrator	Switch	3,709	544	1,272
ATL Switch	SLC Switch	3,975	2,544	3,792
SLC Switch	ATL Switch	6,740	1,344	2,728
E MPS	Concentrator	1,200	104	328
Concentrator	E MPS	1,200	104	328

TABLE D-5: PEAK TRAFFIC - PHASE I RMMS PLUS NADIN IA

D.4 PHASE II RMMS TRAFFIC

The general NAS Sector Maintenance Processor Subsystems will communicate with the Enroute MPS, remote facilities and work centers via the NADIN concentrator. Virtually all general NAS Sector MPS traffic will be local, i.e., originating and ending in the same enroute area. NADIN IA will provide local switching at the concentrator. Hence there will be no increased traffic load on the NADIN backbone due to the Sector MPSs in and of themselves. However, the NADIN concentrator will be required to process this local traffic.

The volume of general NAS Sector traffic depends on the number of remotely monitored facilities. Two scenarios are quantified. First, if there are no RMS facilities beyond Phase I (RCAG and VORTAC) then the traffic for the various RMMS/NADIN and NADIN backbone links is as shown in Table D-6. This level is called Phase II, Scenario I. Second, if the full range of RMS facilities described in Section 2.3.3 are implemented then the general NAS Sector MPSs will result in the total gross traffic shown in Table D-7. This is designated Phase II, Scenario II. These values are based on the following principles:

- General NAS Sector MPSs will receive (from the Enroute MPS) Certification Reports, Alarm Messages, Alarm Ends, Status Requests, Free Format Messages and Administrative Messages (Appendix C),

- General NAS Sector MPSs will send Certification Histories, Status Reports, Free Format Messages and Administrative Messages,

- The number of remotely monitored facilities for a busy general NAS Sector is assumed to be twice the average,

D.5 MODIFIED RMMS CONFIGURATION

The scenarios described in this report are undergoing revisions at this time. Recent modifications to the RMMS program call for homing VORTAC RMC-Fs to the General NAS Sector Maintenance Processor Subsystem (GNS MPS) rather than to the Enroute MPS. In some cases the RMC-C would serve as a buffer to the GNS MPS while in others the RMC-Fs would be connected via multidrop lines directly to the Sector MPS. In addition work center fixed terminals would be connected to their Sector MPS rather than the Enroute MPS. It is also proposed under the new scenario that the Enroute MPS will serve as the site of the enroute area Maintenance Management System (MMS) data base.

LINK		GROSS BITS/SEC
FROM	TO	
Sector MPS	NADIN Concentrator	63
NADIN Concentrator	Sector MPS	186
Enroute MPS	NADIN Concentrator	1,573
NADIN Concentrator	Enroute MPS	739
NADIN Switch	NADIN Concentrator	4,544
NADIN Concentrator	NADIN Switch	944
NADIN Switch	NADIN Switch	3,464

TABLE D-6: GROSS LINK THROUGHPUT IN PHASE II, SCENARIO I

LINK		GROSS BITS/SEC
FROM	TO	
Sector MPS	NADIN Concentrator	400
NADIN Concentrator	Sector MPS	1,200
Enroute MPS	NADIN Concentrator	10,000
NADIN Concentrator	Enroute MPS	4,740
NADIN Switch	NADIN Concentrator	6,700
NADIN Concentrator	NADIN Switch	3,100
NADIN Switch	NADIN Switch	5,630

TABLE D-7: GROSS LINK THROUGHPUT IN PHASE II, SCENARIO II

The effect on NADIN backbone traffic load appears to be a reduction or at most no change from that based on the original program plan. On the one hand shifting VORTAC and work centers to Sector MPSs should reduce the NADIN traffic due to sectors which overlap two or more enroute areas. On the other hand, copies of certification reports and alarm messages for VORTAC facilities in the overlapping sectors will be sent via NADIN from the responsible Sector MPS to the Enroute MPS in the adjacent area. Since no major impact to NADIN throughput/delay seems likely from these recent proposed changes in RMMS configuration, the original quantitative performance results are not recomputed for this altered scenario.

APPENDIX E

RMMS PERFORMANCE REQUIREMENTS

Service requirements which must be satisfied for RMMS data communications are discussed in this appendix. These include performance thresholds in some cases and in other cases include service features.

E.1 PRIORITIES

Alarm and status change messages have the highest priority in the RMMS system. This priority is recognized by the RMS and MPS which give non-preemptive preference to alarms over certification and other reports. Once in NADIN however, all RMMS messages will have priority indicator JJ and be given NADIN priority four.

E.2 TRANSMISSION DELAYS

NADIN must deliver alarm notifications in a timely manner to adjacent MPSs. Delays T described below consist of three components:

T_E = time to enter NADIN from MPS I/O processor

T_N = NADIN end to end delay

T_X = time to exit f NADIN to MPS I/O

The total delay T is given by:

$$T = T_E + T_N + T_X.$$

For alarm and other time critical messages, the average value of delay T shall be no greater than 3 seconds with the value of T less than 5 seconds 90 percent of the time. The alarms

transiting NADIN will almost exclusively be notification to secondarily responsible personnel such as Sector Offices. Primary notification is almost always sent within the originating enroute area. Certification reports and other non-time critical messages will be required to have an average delay T of 5 seconds with T less than 7 seconds 90 percent of the time.

E.3 AVAILABILITY/RELIABILITY

The MPS itself has been specified (Reference 7) to be highly reliable. The MPS/NADIN/MPS connection shall be at least as reliable and available as the MPS itself. This requires specifically that at minimum:

- Availability of NADIN Connection $\geq$ .9996
- Mean Time Between Failure (MTBF) $\geq$ 5000 hours
- Mean Time to Repair $\leq$ 30 minutes
- Periodic Preventive Maintenance $\leq$ 30 minutes per 720 hours

E.4 ACCESSIBILITY

The RMMS recognizes four levels of user authorization (Reference 7). NADIN or any other communications utility used by the RMMS is required to deliver the user's authorization code to the destination MPS. However, the MPS, not NADIN, is responsible for interpreting the authorization code and ensuring that user access is limited to the appropriate level.

E.5 RETRIEVABILITY

MPS to MPS traffic in Phase I implementation will not require NADIN retrievability since this traffic is generally recoverable from the source MPS itself.

E.6 PHASE II AND BEYOND

Several functional requirements can be identified for Phase II and subsequent RMMS implementation. These are:

- File transfers - between Sector, Enroute, Regional and National MPSs,
- Local traffic - NAS Sector MPS traffic which requires only local switching (inside enroute area),
- Terminal access direct to NADIN - locations such as National Headquarters, Academy and others.
- Interactive Freeformat Terminal Communications

Quantification of these requirements will not be possible until the Maintenance Management System and related planning has progressed further. However, Phase II terminal access has been decided. Specifically terminals shall be permitted access to a remote site only if it supplies to its Enroute MPS the complete address of the remote site including the remote site's Enroute MPS address. NADIN will then be required to deliver the message to the appropriate NADIN concentrator for hand off to the remote MPS.

Terminals seeking reports on a remote site will communicate with their (terminals') Enroute MPS which will retrieve the data from the appropriate Sector, Regional or National MPS via NADIN.

APPENDIX F

DELAYS

Delays encountered by messages on NADIN and the RMMS/NADIN interfaces fall into three major categories:

- queueing delays for each link used,
- transmission time on each link, and
- node processing delays.

The total NADIN delay (TD) would thus be calculated as:

$$TD = \left(\sum_{i=1}^{n} (TQ_i + TM_i) + (n+1) \times TN \right)$$

where TQ_i = the queueing delay on link i, in seconds,

TM_i = the message transmission time on link i, in seconds,

TN = the processing time per node, in seconds, and

n = the number of NADIN backbone links involved in the transmission.

The processing delay per node is conservatively estimated to be 50 milliseconds, i.e.:

TN = .05 seconds

The transmission time is determined from:

$$TM_i = GL \times B/C_i$$

where C_i is the transmission rate (capacity) on link i, in bits per second,

and GL and B are the gross message length and bits per character as discussed earlier.

For the links between a switch and concentrator, C_i = 9,600 b/s. On the switch-to-switch link, although the effective capacity is 19,200 b/s, a given message will always be transmitted over a single 9,600 b/s channel. Hence, C_i = 9,600 b/s for the dual-channel link also. Thus, for a NADIN message, consisting of one full frame of 256 characters including headers and trailers:

$$TM_i = 256 \times 1.016 \times 8/9{,}600 = .22 \text{ seconds, for a 9600 b/s link.}$$

Using the above results, the network delay can be expressed as:

$$TD = (n \times .22) + (n + 1) \times .05 + \sum_{i=1}^{n} TQ_i$$

$$= .86 + \sum_{i=1}^{n} TQ_i, \text{ if } n = 3$$

Determination of the queueing delays requires the consideration of several variations. Primary among these is the presence or absence of files to be transferred. Another important variation is the use of single or dual transmission channels. The procedures used to estimate the queueing delays are based on the analyses detailed in Reference 13.

Delays are also calculated for RMMS messages including processing time at an enroute Maintenance Processor System, transit through NADIN to the destination MPS and processing there. The total RMMS delay (TR) is calculated:

$$TR = TD + 2TN + TE + TX$$

where

TD = total network delay as above, in seconds,

TN = processing time per MPS node, in seconds,

TE = entry delay from Enroute MPS to NADIN concentrator in seconds, and

TX = exit delay from NADIN concentrator to Enroute MPS.

The value of TN is again estimated at 50 milliseconds, i.e.:

$$TN = .05 \text{ seconds}$$

For different scenarios the Enroute MPS/NADIN interface speed changes. Delays for various link capacities are computed.

F.1 QUEUEING DELAYS IN THE ABSENCE OF FILE TRANSFERS

On links involving no file transfers, messages can be assumed to arrive at random. For the single-channel links including the MPS/concentrator links, the queueing delay will be approximately:

$$TQ_i = TF_i \times U_i/(1-U_i)$$

where TF_i = the average transmission time, in seconds, per frame on link i,

$= GLF \times B/C_i$

GLF = the gross length, in characters, of an average frame,

and U_i, C_i and B are the link utilization, link capacity and bits per character respectively.

As a conservative estimate, a full frame (245 characters) is considered in estimating TF_i. Thus:

$$GLF = (245 + 11) \times 1.016 = 260 \text{ characters}$$

$$TF_i = 260 \times 8/9{,}600 = .22 \text{ seconds}$$

$$U_i = CGT_i/9{,}600$$

$$U_i/(1-U_i) = CGT_i/(9{,}600-CGT_i)$$

$$TQ_i = .22 \times CGT_i/(9{,}600-CGT_i) \text{ seconds, for the single-channel links,}$$

where

$$CGT_i = \text{cumulative gross throughput on link } i.$$

The above approximation assumes random (Poisson) message arrivals and a standard deviation of frame length that is equal to the average frame length (a conservative assumption). The bases for this approximation can be found in most queueing theory texts (see, for example, Reference 14, Chapter 3).

Files will be transferred in both directions on the dual-channel switch-to-switch link. Peak-period queueing delays for those links would thus be determined as discussed below.

F.2 QUEUEING DELAYS IN THE PRESENCE OF FILE TRANSFERS

The relatively large file (or report) transfers introduced by FSAS and AFC traffic can create intervals of several minutes during which a link will be transmitting at essentially full capacity. The assumption of random message arrival, used above, is therefore not applicable during such intervals. These intervals will be the real peak periods for NADIN.

As recommended in the Level IA Study (Reference 13) and Reference 15, it is assumed that a discipline will be implemented at the NADIN switches, such that large file transfers will not unduly delay other message traffic. This has been modeled as follows:

- Consider the NADIN backbone link connecting a switch (Node A) and an associated concentrator or the other switch (Node B). For this link, Node A will effectively maintain a number of output message queues, one for each output port at Node B (plus a top priority message queue, which need not be considered here).

- The discipline at Node A will cycle through the queues for Node B, processing each queue in turn.

- If a queue (Queue I) is empty, it is instantly passed over.

- If Queue I is not empty, one frame from that queue is transmitted to Node B and processing passes to Queue I + 1. Any other message frames in Queue I must await processing in subsequent cycles.

The mean queueing delay for the first or only frame in a randomly arriving message, under such a process can be determined approximately (see Reference 15) as:

$$TQ_i \quad = \quad .75 \times TC_i$$

where

$$TC_i \quad = \quad \text{mean time per cycle through the queues for link i.}$$

TC_i is determined by noting that during the file transfer interval the full capacity of the link is utilized ($U_i = 1.0$) and a relatively fixed amount of time (TF_i') is devoted in each cycle to the transfer of the file frame(s).

If U_i' is the utilization associated with the random (non-file transfer) traffic,

then

$$TF_i'/TC_i = 1 - U_i'$$

i.e., the fraction of the cycle time devoted to file transfer is equal to the fraction of the capacity not used for random traffic.

Thus:

$$TC_i = TF_i'/(1 - U_i')$$

$$U_i' = (CGT_i - GFT_i)/C_i$$

where GFT_i = gross throughput requirement for file transfers on link i (averaged over the peak hour)

and CGT_i and C_i are the gross throughput and capacity for link i, as discussed earlier.

Combining the above expressions:

$$TQ_i = .75 \times TF_i' \times C_i/(C_i + GFT_i - CGT_i)$$

For the message traffic considered in this study, two "file transfer" queues would exist, one for the scheduled FSAS files and the other for the long (30,000 character) AFC reports. Table F-1 summarizes the throughput on each NADIN link associated with such transfers. The values shown in that table are the values for GFT_i and for U_i', the random message utilization.

Since $GFT_i = 0$ for concentrator-to-switch links and MPS/NADIN links, queueing delay for those links would be determined as described in F.1 above.

For the switch-to-concentrator links, both file transfer queues may contain frames simultaneously. Thus:

$$TF_i' = 2 \times TF_i = .44 \text{ seconds}$$

where TF_i = the full frame transmission time (.22 seconds), discussed earlier.

and TQ_i = $.75 \times .44 \times 9{,}600/(9{,}600 + GFT_i - CGT_i)$

= $3{,}168/(9{,}600 + GFT_i - CGT_i)$ seconds.

Determining TF_i' for the switch-to-switch links is not as direct. Since there are two 9,600 b/s channels, a randomly arriving message can be transmitted over the second channel

NADIN BACKBONE LINK		ENVIRONMENT	FILE TRANSFER (B/S) GROSS	RANDOM MSG. UTILIZATION
FROM	TO			
Switch	Concentrator	NADIN IA	1,448	.323
		Phase I	1,448	.357
		Phase II - Scenario I	1,448	.357
ATL Switch	SLC Switch	NADIN IA	1,448	.075
		Phase I	1,448	.123
		Phase II - Scenario I	1,448	.123
SLC Switch	ATL Switch	NADIN IA	184	.116
		Phase I	184	.133
		Phase II - Scenario I	184	.133
Concentrator	Switch	NADIN IA	0	0
		Phase I	0	0
		Phase II - Scenario I	0	0

TABLE F-1: PEAK HOUR FILE TRANSFER THROUGHPUT VS. RANDOM MESSAGE UTILIZATION

while a file frame is being transmitted on the first. It is convenient therefore to treat this case as if there were a single 19,200 b/s channel; i.e.:

$$C_i = 19{,}200$$

$$TF_i' = m \times 260 \times 8/19{,}200 = m \times .11$$

where m = the number of file queues used.

Note however that the value of TF_i is based on the speed of a single channel, i.e, 9600 b/s.

Thus, for the Atlanta to Salt Lake City link:

$$TQ_i = .75 \times .22 \times 19{,}200/(19{,}200 + GFT_i - CGT_i)$$

$$= 3168/(19{,}200 + GFT_i - CGT_i) \text{ seconds.}$$

For the Salt Lake City to Atlanta link:

$$TQ_i = .75 \times .11 \times 19{,}200/(19{,}200 + GFT_i - CGT_i)$$

$$= 1584/(19{,}200 + GFT_i - CGT_i) \text{ seconds}$$

F.3 DELAY SUMMARY

The above expressions have been used to determine the average queueing delays for each NADIN backbone link and the Enroute MPS/NADIN concentrator links under various loading environments. The results of these calculations are shown in Tables F-2 and F-3 respectively.

The queueing delays shown in Tables F-2 and F-3 are used to calculate NADIN and RMMS delays as discussed earlier. Thus, for example, an RMMS message transmitted from an Enroute MPS in Memphis to an Enroute MPS in Fort Worth will encounter the following delays in Phase I:

ENVIRONMENT	FILE TRANSFER	LINK QUEUEING DELAYS (SECONDS)		
		NC TO NS	NS TO NS	NS TO NC
NADIN IA	Y	.03	.19	.49
	N	.03	.03	.11
Phase I	Y	.04	.20	.52
	N	.04	.04	.13
Phase II, Scenario I	Y	.04	.20	.52
	N	.04	.04	.13

NC = NADIN Concentrator

NS = NADIN Switch

TABLE F-2: NADIN BACKBONE QUEUEING DELAYS TQ_i

ENVIRONMENT	E MPS TO NC (SEC)		NC TO E MPS (SEC)	
	2400 B/S	4800 B/S	2400 B/S	4800 B/S
Phase I	.06	-	.06	-
Phase II, Scenario I	.77	.1	.18	.04

E MPS = Enroute MPS

NC = NADIN Concentrator

TABLE F-3: RMMS/NADIN QUEUEING DELAYS

- Node Processing Delays (6 nodes) = 6 x .05 = .30
- Transmission Delays (3 NADIN links + 2 access links) = 1.46
- Queueing Delays (5 links):

E MPS to NC	=	.06
NC to NS	=	.04
NS to NS	=	.20
NS to NC	=	.52
NC to E MPS	=	.06

Total Delay = 2.64

Table 4-2 shows the total end-to-end delays in NADIN from concentrator to switch to switch to concentrator. Delays are shown for the average RMMS message (average gross length = 120 characters) and for a single full frame message (gross length = 256 characters). Table 4-3 shows the total end-to-end average delay for an RMMS message from an Enroute MPS, through NADIN as described above, to a remote Enroute MPS.

APPENDIX G

HOST-TO-HOST PROTOCOL ISSUES IN THE RMMS AND MMS

The RMMS and MMS each consist of a number of processes running on geographically dispersed hosts (MPSs) communicating via an intervening network (NADIN). The role of the lower three protocol layers (physical, link and network) in the ISO model is to guarantee delivery of data from Data Terminal Equipment (DTE) to Data Terminal Equipment, i. e., computer (or front-end) to computer. But this is not sufficient. A higher layer, the transport layer (References 6 and 12), has the job of providing a reliable and efficient end-to-end delivery of data between MPS processes rather than just between machines. To ensure that exchanged data can be understood and acted on effectively is the role of the higher layers, particularly Layer 6, the presentation layer, and of course finally Layer 7, the application layer.

In the subsequent sections, Layer 4, the protocol layer, is discussed in more depth. In addition, several issues in the presentation layer are identified for future consideration in RMMS and MMS program implementation.

G.1 THE TRANSPORT LAYER IN GENERAL

The transport layer described here is the means by which MPS processes establish and terminate connections with each other, handle buffering and flow control, recover from errors and perform other related functions. This layer defines a set of transport addresses or sockets through which interprocess communications occur. For example, transport addresses in NADIN would be specified by NADIN node (concentrator), physical port and socket (or logical port) number. On a given MPS each process will correspond to a unique socket number. A well designed transport layer will enable processes to communicate in an error free manner without regard to the characteristics of the underlying communications medium or subnetwork.

The basic primitives in nearly all transport protocols include at a minimum CONNECT, LISTEN, CLOSE, SEND, and RECEIVE. A CONNECT request announces that a process wishes to establish a connection or association with another named process. A LISTEN request indicates a process' willingness to accept connections. A CLOSE request terminates

connections. A RECEIVE primitive indicates that a process is willing to receive and has allocated buffers. A SEND call transmits the contents of a buffer on the indicated transport connection. More detailed discussions of the use and implementation of transport protocols is to be found in References 6 and 12.

G.2 PRESENTATION LAYER ISSUES (LAYER 6)

This layer provides additional services to facilitate the useful exchange of information between processes. For MPS-to-MPS communication, the most important of these is file transfer service, although there may someday be need for cryptographic transformation. Text compression is another service of Layer 6 which could be useful to RMMS/MMS. The function of text compression is to reduce the number of bits which must be sent through the communications medium. Since bandwidth is becoming more expensive while computing power is becoming less expensive, this is a possible cost cutting strategy for any distributed system.

G.2.1 File Transfer Protocol

Files can be transferred from machine to machine in a homogeneous environment without much concern. However, in a heterogeneous environment this task is much more difficult. It is the function of the file transfer protocol to achieve this transfer smoothly between incompatible machines. Appropriate conversions must be performed by the file transfer protocol. Initially the MPSs will all be Tandem T16s talking only to each other. Whether or not the general NAS Sector MPSs will also be Tandem is not yet determined. However, even if they are, it is likely that at some point in the future interconnections between the MPSs and other host computers such as the 9020R will be desired. Early planning and development of a file transfer protocol (perhaps provided by NADIN in the future) would facilitate this interconnectivity.

APPENDIX H

NADIN AND RMMS/MMS INTERFACE CONTROL DOCUMENT

H.1 INTRODUCTION

H.1.1 Purpose

This appendix describes the interface requirements which must be incorporated in the NADIN and RMMS/MMS designs in order to exchange RMMS/MMS data traffic through NADIN. It is anticipated that each MPS will interface with a NADIN concentrator. The hardware and procedural characteristics described herein shall be provided at each interface with NADIN.

H.1.2 Organization

This appendix provides a brief overview of the interface characteristics, followed by specific physical, link and transport levels of interface requirements that shall be incorporated in the NADIN and RMMS/MMS implementations.

H.1.3 Assumptions

In the event of NADIN Switching Center failure it is assumed the entire RMMS requirement will be supported through the surviving NADIN switching center. (NADIN Concentrators will rehome on the surviving switch automatically).

H.1.4 Technical Summary

This interface shall support data exchanges of 2400 b/s, over bit serial synchronous channels. The channel shall be implemented in a full duplex DTE-to-DTE configuration per EIA RS-449 (balanced) standards (Figure H-1). Link control shall be in accordance with FED-STD-1003 (ANSI X3.66-1979, Advanced Data Communication Control Procedure,

RS-422 DRIVERS AND RECEIVERS WILL BE USED

RS-449	CCITT V.24	DESCRIPTION
SG	102	SIGNAL GROUND
RD-A'	104	RECEIVED DATA
RD-B'		
RR-A'	109	DATA CHANNEL RECEIVED LINE SIGNAL DETECTOR
RR-B'		
SD-A	103	TRANSMITTED DATA
SD-B		
RS-A	105	REQUEST TO SEND
RS-B		
ST-A'	114	TRANSMITTER SIGNAL ELEMENT TIMING
ST-B'		
RT-A'	115	RECEIVER SIGNAL ELEMENT TIMING
RT-B'		

- THE MPS SHALL PROVIDE THE DATA SIGNAL TRANSPOSITION FOR CCITT CIRCUITS 104 TO 103 AND CIRCUITS 105 TO 109.
- A 37 PIN RS-449 DTE CONNECTOR SHALL BE SUPPLIED ON NADIN
- BECAUSE RS-422 DRIVERS AND RECEIVERS ARE BEING USED THIS INTERFACE WILL NOT BE COMPATIBLE WITH RS-232
- CLOCKS FROM MPS

FIGURE H-1: MPS TO NADIN RS-449 DIRECT INTERFACE

ADCCP) with options 1, 2, 7 and 11 implemented. The normal operating mode shall be balanced asynchronous (BA). The NADIN and MPS elements shall operate as combined stations. Data shall be exchanged on a frame basis. Frame format is not specified in this ICD. Data may be in any code or as a stream of bits.

H.2 PHYSICAL INTERFACE

H.2.1 Electrical and Mechanical Interface

The mechanical interface between the NADIN-MPS shall be in accordance with EIA Standard RS-449 with the electrical interface conforming to RS-422 balanced voltage.

H.2.2 Communications Facility

The communication facilities for the NADIN-MPS interfaces can be one of two types: local where the NADIN node is located within the distance limits of the electrical/mechanical interface (about 1000 meters) and remote where the NADIN node is located beyond the limited distance. In either case the interface shall be a synchronous communication full-duplex channel.

H.2.2.1 Local Facility

For NADIN nodes locally located from the Enroute MPS, the communication facilities shall be twisted pair cables. Limited distance modems may be used. The cable shall be supplied by the RMMS program. When interconnecting by cable without modem, the clock signal shall be provided by the MPS; data signals (RD and SD) and timing signals (RT and ST) shall be transposed by the cable.

H.2.2.2 Remote Facility

For NADIN nodes remotely located from the Sector MPS, the communication facilities shall be 4-wire circuit of conditioned type 3002 and modems in accordance with FED-STD-1005 or FED-STD-1006. The modems shall be capable of handling full duplex, synchronous transmissions at 2400 or 4800 b/s. Spare modems shall be available in the event of modem failure.

H.3 LINK CONTROL PROCEDURE

The procedure utilized on this interface shall be in accordance with the procedures presented in FED-STD-1003 and expanded herein. This is a two-way simultaneous non-switched, point-to-point protocol employing code and byte independent transmission. The Balanced Asynchronous (BA) Mode shall be used, without extension of the Control Field. The RSET, SREJ, UI, UP, RIM and SIM commands and responses shall not be used.

H.3.1 Class of Operation: Balanced Asynchronous

Under the Balanced Asynchronous procedure, each of the two stations on a point-to-point link is a combined (primary and secondary) station. As appropriate, either of the two stations can take on the primary role (send commands), causing the other to take on the secondary role (send responses).

H.3.2 Frame Structure

The unit of transmission under ADCCP is the frame. Each frame transmitted from any type of station must contain an opening flag sequence, address field, control field, information field, frame check sequence, and ending flag sequence. The information field need not be included. Messages used for link control only, however, if present, must not exceed a maximum of 2000 bits. The Control Field extension shall not be used.

H.3.3 Addressing

ADCCP requires that a unique address be associated with all secondary stations on a link (this includes all combined stations). Any transmission to or from a secondary station shall contain the address of that station in the address field.

H.3.3.1 Address Field

The ADCCP address field shall use a single octet where the least significant bit of each address shall be 1. The address octet shall be as follows:

SECONDARY STATION	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8
MPS	1	1	0	0	0	0	0	0
NADIN CONCENTRATOR	1	0	0	0	0	0	0	0

H.3.3.2 Global and Null Address

The global address, eight "1" bits shall not be used since no switched lines will be used in the NADIN and RMMS interface. The null address, eight "0" bits, shall be used for testing purposes only and shall be ignored by the secondary station function. The null address can be used in situations where it is desired to exercise a station's transmit abilities without requiring station action or reply.

H.3.4 Link Control Functions

ADCCP provides for a variety of control functions. These are defined as a series of basic commands and responses together with a series of optional commands and responses. The ADCCP Standard in FED-STD-1003 describes these functions in detail. The following outlines those that shall be implemented for the RMMS and NADIN interface.

H.3.4.1 Basic Functions

The basic control functions include both commands (i.e., from primary stations) and response (i.e., from secondary stations). The following identifies these functions as they apply to RMMS and NADIN:

FUNCTION	TYPE*	MEANING
I	C&R	Information being transferred.
RR	C&R	Receive Ready
RNR	C&R	Receive Not Ready
FRMR	R	Frame Reject
SABM	C	Set Asynchronous Balanced Mode (BA procedures only)
DISC	C	Disconnect
UA	R	Unnumbered Acknowledgement
DM	R	Disconnected Mode

*C= Command; R = Response

In addition there is a basic command RSET (Reset) for BA procedures which shall not be used.

H.3.4.2 Optional Functions

ADCCP provides eleven options for adding or deleting control functions. For the RMMS and NADIN interface, options 1, 2, 7, and 11 shall be implemented and are described as follows:

OPTION#	ADD/ DELETE*	TYPE*	FUNCTION	MEANING
1	A	C&R	XID	Exchange Identification
	A	R	RD	Request Disconnect
2	A	C&R	REJ	Reject
7	A	C&R	—	Multiple Octet Address
11	D	C	RSET	(Delete the Basic Reset Command)

*A = Add Function; D = Delete Function; C = Command; R = Response

H.3.5 Link Control Timers

Often an expected acknowledgement or response is not received due to transmission losses or FCS errors (for messages in either direction). To help detect such conditions efficiently, time-out functions shall be implemented. Time-out functions shall (1) initialize a timer when a transmission requiring an acknowledgement or response is sent, (2) stop the timer when the acknowledgement or response is received, and (3) note a time-out condition when a prespecified time has elapsed without the expected acknowledgement or response having been received. If the time-out condition occurs, recovery actions shall be taken, generally involving retransmission of the frame that started the process.

H.3.5.1 Timer Functions

The time-out functions specified in this section represent the minimum requirements and do not preclude other time-out functions. The necessary timers and their functions are:

- Poll Timer - used at a primary/combined station to detect the lack of a response to a poll. Also used to delimit the check point cycle in the absence of poll response.

- Information Ack Timer - used to detect missing or unacknowledged information frames that will not show up as an out-of-sequence exception. This timer is important if and when a single or final information frame is transmitted which does not contain a P bit set to "1".

- Sent REJ Timer - used to detect the lack of receipt of response to an REJ command/response. Similar timers may be implemented for other command/responses in addition to REJ.

- Busy (RNR) Timer - used by a secondary/combined station to determine when it can resume sending I or UI frames to a primary/combined station that has sent an RNR command and has not cleared the busy condition by other means.

- Idle Timer - used by a primary/combined station to insure that a secondary/combined station is polled if there is no transmission in either direction for a specified time duration.

H.3.5.2 Timer Values

The establishment of timer values shall be postponed until system implementation. However, at a minimum timers shall be adjustable in increments of .01 seconds over the range 0 to 300 seconds. Recommended initial settings are shown in Table H-1 in terms of recommended upper and lower limits for initial timer settings.

H.3.5.3 Acknowledgement

Each time a station receives an information or supervisory frame, it expects acknowledgement (through the N(R) parameter) of information frames it transmitted. To facilitate retransmission of unacknowledged information frames, each station shall implement checkpoint recovery, as follows:

- A checkpoint cycle is defined for a primary/combined station as the period between the transmission of a frame with the P bit set to 1 and either (1) the next receipt of a frame with the F bit set to 1 from the secondary to which the poll bit was directed, or (2) the expiration of the poll timer, whichever occurs first. In balanced operation a combined station will not initiate checkpoint retransmission upon the receipt of a frame with the P bit set to 1. (A cycle does not end with an unnumbered frame, however.)

- At the end of each cycle, the station will retransmit any unacknowledged frames (per the value of N(R) received) that had been transmitted before the start of the cycle, and any subsequent frames transmitted. This is referred to as checkpoint retransmission.

- If an REJ frame with the P/F bit set to 0 is received during such a cycle, actions pertinent to the REJ condition, rather than checkpoint retransmission, will be implemented.

- See ADCCP, ANSI X 3.66 - 1979 for further details and exceptions.

TIMER	LOWER LIMIT	UPPER LIMIT
Poll	1	4
I-Frame response	2	4
Sent REJ	1	4
Busy (RNR)	5	120
Idle	1	30

a) 4800 bit/sec link

TIMER	LOWER LIMIT	UPPER LIMIT
Poll	.5	2
I-Frame response	1	2
Sent REJ	.5	2
Busy (RNR)	.5	120
Idle	1	30

b) 9600 bit/sec link

TABLE H-1: TIMER VALUES - SUGGESTED INITIAL LIMITS (SECONDS)

H.3.5.4 Busy Condition

When a station temporarily cannot receive or continue to receive information frames due to internal constraints (e.g., buffer limitations), it should notify the transmitting station by sending an RNR Command/Response and report its condition to the supervisor function. Upon receipt of an RNR frame, a station shall not transmit new information frames to the busy station. Clearance of the busy condition shall be reported by transmission of an RR, REJ, SABM, or UA frame with or without the P/F bit set to 1; or transmission of an information frame with the P/F bit set to 1. If the busy condition has not been cleared by other means, the expiration of the busy condition timer enables a secondary/combined station to resume transmission of I or UI frames to the primary/combined station. e system supervisor function shall be notified when the busy condition is cleared.

H.3.6 Error Control

H.3.6.1 Frame Check Sequence

The frame check sequence (FCS) shall be a 16-bit (2 octet) number generated at the transmitting station by applying a special algorithm to the string of bits that make up the address field, the control field and (if present) the information field, prior to zero insertion. The value of the FCS shall be determined and transmitted as part of each frame.

The receiving station, after removing the flag sequences and the inserted zeros, shall determine if the received FCS is consistent with the remainder of the transmission. Inconsistency implies an error in transmission and shall cause the transmission to be unacceptable.

Appendix D to ANSI X3.66-1979 defines the FCS in detail and suggests techniques for implementing this process.

H.3.6.2 Frame Check Sequence Error

Errors introduced during the transmission of a frame will almost always cause an FCS error, i.e., cause the received value of the FCS to differ from the expected value. Frames with such an error shall be discarded.

H.3.6.3 Frame Reject Condition

When a frame is received with no FCS error, but contains (1) an invalid control field, (2) an invalid N(R) or (3) an information field with more than 2000 bits, a frame reject condition exists. A secondary station, upon detecting such a condition, shall notify the primary station with a FRMR response. A primary station upon detecting such an error or upon receiving an FRMR response shall transmit a mode setting command (SABM, or DISC). Higher level recovery functions may also be implemented by the primary station.

H.3.6.4 Frame Sequence Error

Whenever a station receives an otherwise error-free information frame, it shall check to insure that the value of N(S) corresponds to the receive variable R(A). If the two are not identical, a frame sequence error has occurred. At the earliest opportunity the receiving station shall transmit an REJ frame to the original transmitting station, with N(R) set to R(A). The information field(s) from the erroneous frame and any subsequent information frames from that transmitting station shall be discarded, until one with N(S) equal to R(A) is received. Other control information (e.g., the P/F bit and N(R)) from those frames will be used. The original transmitting station, upon receiving the REJ frame shall retransmit the erroneous frame and any subsequent information frames (in order) at the earliest opportunity.

H.3.7 Recovery

After three attempts to establish communication or recover an errored frame, in either direction, the primary function (of the combined station) shall declare the link inoperable and produce a fault report to the link supervisor function.

H.4 NETWORK LEVEL

MPS to MPS data shall be transmitted as packets in accordance with the X.25 standard of CCITT (Reference 11). In particular, packet headers shall be appended by the MPS Data Terminal Equipment (DTE) for handoff to the Data Communications Equipment (DCE).

APPENDIX I

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